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Remote Collaboration solution for a Physiotherapist

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REMOTE COLLABORATION SOLUTION FOR A PHYSIOTHERAPIST

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Credit awards unknown Thesis proposal submitted for the commencement of a *Masters of Human Interface Technology* degree in HCI

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Remote Collaboration solution for a Physiotherapist
(Assisting stroke survivors performing rehabilitation exercises from their home environment through Virtual Reality)

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I would like to dedicate my thesis to my family for their love, support and belief placed within me during this part of my journey through life. I would also like to include Thomas Furness in this dedication. It was Tom who seen something in me and through his advice and effort I was given a rare opportunity in life. I am forever grateful for this experience given to me.

Declaration of Authorship

I, Jonathan Martin Charles O'Duffy, declare that this thesis titled, 'Ghost - Remote Collaboration solution for a Physiotherapist' and the work presented in it are my own. I confirm that:

- This work was done wholly or mainly while in candidature for a research degree at this University.
- Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated.
- Where I have consulted the published work of others, this is always clearly attributed.
- Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work.
- I have acknowledged all main sources of help.
- Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself.

Signed: Jonathan O'Duffy

Date: 19-5-2015

Abstract

This thesis explores the "Smart Idea" of Ghost, a technology to enhance the health and wellbeing of world citizens by providing a better way of delivering therapy to patients. Ghost has the novel affordance wherein a physiotherapist or healthcare professional is able to 'virtually' inhabit the body of a remote patient to instruct and guide that patient's rehabilitation exercises. From the patient's perspective, the remote therapist is seen as a life-size "ghost" (or virtual image) that appears to originate or emerge from within the patient and guides their actions; hence the name: Ghost.

The focus of this thesis in two areas: 1) the selection and evaluation of technologies that could be designed and integrated into prototype configurations that create the Ghost affordances; and 2) potential ways of using the prototype in therapy especially as a serious game. Based on this research, future research would evaluate these configurations in clinical trials. Based on studies in traditional and Virtual Reality rehabilitation techniques, several systems were designed with a focus on Stroke Rehabilitation.

Accordingly, this thesis investigates several key components needed in the Ghost framework: tracking, display, and interaction constructs; as well as its potential as a stroke rehabilitation tool for Physiotherapists and Stroke patients with a focus on being a force multiplier in the future.

To assess the efficacy of such a hypothetical system the author first developed an experimental prototype that combines several tracking and display solutions alongside several visual effects for adherence; and then second, conducted experiments using this prototype to determine the optimum configuration for tracking/display/interaction constructs based upon usability and cost.

Evaluation of the prototype system shows that the Kinect v2 tracking system paired with the Oculus Rift Head-mounted Display is rated as the best technology configuration by non-clinical users. This is due to the level of immersion and sense of depth provide by the Oculus along with the natural gestures provide by the Kinect V2. The Myo armband was rated as the least desirable tracking approach due in part because it is a new device and requires user specific setup. The Large Display, while rated the lowest amongst the display conditions, was highlighted by participants to

still be acceptable. Amongst the visual effects tested for collaboration and interaction constructs, it was found that the Ghost Occlusion effect, applied to either the remote or local collaborator, would be the most suitable. This would reduce the problems associated with overlaying two visual fields on top of each other that occurs when using no visual effects. A Moodle website was implemented in an attempt to collaborate with the target user group due to the groups time restrictions. While no statistical evidence was gained (due to low participant numbers) the author feels this is still a valuable approach to be explored in the future and can succeed with a greater level of advertising and campaigning. Finally, the Butterfly game created for stroke treatment and its various components have shown potential for the use in rehabilitation. The evidence gained from this research project is based on healthy participants; Further investigations will need to be conducted with stroke patients to verify results.

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Glossary

Here is a list of keywords and their explanations that may help in the reading of this thesis:

- **Gamification** is the process of turning an exercise or task into a meaningful context within a game environment.
- **Serious Games** is a computer generated game with a task, purpose or meaning that is connected to the real world
- **Computer-Aided Interaction** is a method of completing a task with the help of a computer.
- **Augmented Reality** superimposes computer-generated content within the user's field of view of the real world.
- **Telepresence** is the sense of being elsewhere through the use of Virtual Reality
- **Bioinformatics** the science of collecting and analysing complex biological data.
- **Computer Graphics** refers to image data generated through the use of a computer.
- **Computer Vision** is the method for analyzing and understanding images.
- **Ghost** is a method for allowing two people to interact intimately with each other, such as a therapist and patient.
- **Image Processing** is a method of analysing and manipulating digital images.
- **Virtual Reality** is a computer generated content of a three-dimensional environment which the user can interact with as if it were real.
- **Virtual Reality Simulation** is an environment or task that is re-created

within a computer generated environment that the user can interact with.

- **Networking and Communication** is the connection of computers to each other to allow for the exchange of data.

- **Biomedical Instrumentation** refers to a broad range of devices that are used for medical purposes.

- **Medical Devices** is an instrument used to diagnose, prevent or treat a condition without the use of chemicals on an individual.

- **Rehabilitation Engineering** is the process of applying engineering design to create technology solutions to help individuals with disabilities.

- **Video Communications** is a technology solution that allows individuals to hold a face to face meeting without having to be in the same location.

- **Usability** is a an attribute used to assess how easy user interfaces are to use.

- **Physiotherapy** is the treatment of an individual's treatment through the use of physical methods over drugs or surgery.

- **Rehabilitation** is the act of restoring something to its original state.

- **Infarcts** is a type of ischemic stroke resulting from a blockage in the blood vessels which supply blood to the brain.

- **Therapy** is a treatment with the purpose to heal or relieve an individual's condition.

- **Educational Technology and Computing** is the effective use of technology in aiding learning.

- **Tapu** means sacred in Māori.

- **Hapū** means sub-tribe, clan in Māori.

- **Whānau** means extended family in Māori.

- **Iwi** means tribe, nation in Māori.

- **Pākehā** means non-Māori descent.

- **Marae** is a courtyard or complex of a Māori meeting house.

Abbreviations

- **VR** Virtual Reality
- **VRR** Virtual Reality Rehabilitation
- **AR** Augmented Reality
- **6-DOF** 6-Degrees of Freedom
- **Flock** Ascension Flock of Birds
- **Pi** Raspberry Pi
- **Myo** Myo Armband
- **Oculus** Oculus Rift Development Kit 1
- **HMD** Head Mounted Display
- **AI** Artificial Intelligence
- **AOT** Action Observation Treatment
- **CIMT** Constraint-Induced Movement Therapy
- **PD** Parkinson Disease

Acknowledgments

I would like to thank and acknowledge the contributions of my supervisors: Thomas A. Furness III, Mark Billinghurst, Stuart Smith, Marcus King and Joyce Alberts.

Tom brought me to HITLab NZ and shared his vision for the Ghost project which gave me a direction for my Masters. Mark shared his insights into user experience and was always kind to me. Stu gave me the opportunity to work on creating serious games for Parkinsons disease from which I took the lessons learnt and applied them to the stroke game. Marcus helped give insight into what is a stroke and the technology solutions that was being implemented. Joyce helped give a deeper understanding about strokes and created a path to engage with medical staff and Burwood Hospital.

I am grateful for all my supervisors knowledge, wisdom and advice that they have shared with me. Without them, Ghost would not be what it is today.

I would to thank Agnieszka Szóstek for all her advice and insightful approach into designing Ghost. Her input was valuable in the creation of Ghost. Lukasz Szóstek was kind enough to show me the Knee rehabilitation solution he was involved in which was extremely helpful.

Adrian Clark has been an awesome support throughout Ghost. His contributions and feedback were greatly appreciated, especially in the technical side of things: his setup of Raspberry Pi and the Ascension Flock of Birds saved me weeks of development time. I also appreciated the time he took out of his day when I needed a break from work and someone to talk to.

Philip Lamb was helpful with providing the code and framework he used when working with Ascension Flock of Birds.

Gun Lee helped structure the user testing and data analysis. Jonathan Wang came up with the idea for using Moodle for online user testing. Eduardo Sandoval provided valuable feedback on my user testing which ensured I got valuable data.

Mitchell Adair has been instrumental in helping document my thesis work. Everything from video editing to photography was done by Mitch. With his help I was able to record visually this research for future generations. Thanks Mitch.

A special thank you goes out to all the other students and staff at HITLab NZ. It was an amazing place to do my masters research. The Lab felt more like a family environment than a work environment. I will miss hanging out and will look back fondly on our time spent together. I wish all you guys the best with your own research and journey through life. I look forward to our paths crossing again in the future.

For anyone considering what tools to use for their own projects, I would like to recommend Unity3d. The community support and documentation are amazing. The individual developers who create plugins for Unity3d also provide valuable feedback and advice on how to implement various features. This means that you can focus on the purpose of your project and not the implementation difficulties normally faced in software development.

Although not a part of this project, I would like to acknowledge Andrew Spilling from UTAS School of computing. During my undergraduate degree I worked as a IT Helpdesk officer with Andrew as my supervisor. He taught me valuable life lessons among which was how to solve problems and help people. I use these skills everyday and they were invaluable in completing my masters degree. Thank you Andrew.

Finally. I would like to thank everyone that was involved in Ghost: from the presentations to medical staff, all the way to the participants that were involved and volunteered their time for my user testing.

Without help from all these people. None of this would have been possible.

1. Introduction

1.1. Problem Domain

There is an unpredicted and growing burden placed on current healthcare services around the world. As lifestyles of the average person have grown in quality, so has life expectancy. While beneficial to the individual, across a larger aging population this creates new problems around how to deal with a concomitant growth in age-related health conditions, many of which require physical therapy.

New Zealand currently spends NZ$5.6B annually on musculoskeletal disease [37]. However, there is just a 30% increase in funding planned between now and 2026 to deal with a 200% demand increase, so it seems unlikely that New Zealand healthcare will be able to handle this burden. Even now the current healthcare services lack the needed resources.

In our research we focus on a small section of the population - stroke survivors, who make up $550,000,000 of the annual expenses. Of these, 85% report a loss in hand or arm motor control, which is enough to hinder their day-to-day activities [38]. The current solution to this problem is to have the individuals perform reaching and grasping tasks; however, it is estimated that 75% cannot perform these tasks. Between 300-1000 repetitions are needed daily to help in recovery but based on time constraints, whereas physiotherapists can only carry out 20-50 repetitions on average with each patient [39]. Individuals are also different, so each training session has to be customized to suit their needs.

Physiotherapists (therapists) face several problems when dealing with stroke survivors [40–42]:

- **Hospital Resources:** Therapists are told to focus on getting patients to be able to walk, so they can be sent home, freeing up space for the next patient. However this means that upper body recovery is often not addressed.
- **Time:** Due to limited resources and number of patients they must treat daily, therapists are restricted by the amount of time they can spend on any given

patient.

- **Distance:** When therapists have to travel to do home visits for patients, travel logistics limit how many patients they can treat in a given day. This is in addition to the reduced time they can spend with each patient due to patient loads. So inevitably, home visits and call-outs to patients have become restricted.

- **Performance/Canonical:** Therapists face the problem that patients may perform their assigned exercises incorrectly in the home environment, which, in turn, can cause injuries to the patient and lengthen the recovery process.

- **Motivation:** A major challenge therapists face is motivation and retention of instructions among their patients. The majority of patients are simply not motivated to do their exercises at home to regain lost abilities.

- **Overambitious:** Although rare, some therapists face the problem of patients' doing too much, injuring themselves and thereby lengthening the recovery process.

- **Monitoring:** Therapists also have the problem of not knowing when and how often a patient is performing their exercises.

Stroke survivors face a number of problems during their rehabilitation:

- **Morale and Frustration:** Stroke patients often have to deal with the frustration of losing some of their motor and cognitive abilities. At the same time they also need to stay motivated and not give up during their rehabilitation. Depression is very high and common amongst stroke survivors.

- **Therapist Access:** Gaining access to therapy treatment is rather limited and many of their assigned rehabilitation routines have to be done from their home.

- **Logistics:** If patients have a therapy appointment at the hospital or other clinical location there is the logistical challenge of how to get there. Maybe a family member has to drive them and/or take time off of work. In the case of people living in remote communities, travel to a clinic can turn into a several hour journey or longer.

- **Family:** Stroke recovery and therapy can impact the patient's family, especially if they are a parent looking after children. They may have to change its lifestyle or daily routine to accommodate the family member who has had a stroke.

Māori in particular also face additional challenges:

- **Higher Probability** The chances of stroke for Māori people are 3 times higher compared to non Māori's.
- **Tapo** The head is sacred to the Māori and so having a stroke were part of the head/brain is damaged has a large emotional impact on them.
- **Family** They are close to their families and rely on each other. If the head of the house has a stroke it impacts the rest of the family. Family members often quit jobs to take care of them and younger generations don't know how to react and can rebel about the loss of family leadership.
- **Tribe** The Māori iwi pride themselves in looking after their own people. They would like to have a Māori rehabilitate on the community grounds were they can take care of everyone instead of sending them off to the white peoples' rehabilitation centres.

The following is a typical treatment sequence that a patient might face after suffering a stroke (treatments varies from patient to patient especially depending on the type of stroke):

Assessing the Type of stroke: The patient is checked to see if the stroke is a rupture or a block and on which side of the brain.

Post surgery: Check the patient's balance by trying to get them to sit up in bed.

Assessment: Assess the extent of the damage and what the patient is able to do and not do.

Walking: The therapist focuses on getting the patient to walk so they can be sent home and begin the next stage in their rehabilitation program.

Home Rehabilitation: The patient is shown exercises that they must do in order to regain lost abilities.

Rehabilitation Centres: Assignment to a specific rehab center if the patient is fortunate to have ready access to these facilities to help in their recovery.

Checkups: The patient is checked by a therapist at assigned appointments to measure their progress. If they live in remote communities or areas this can involve a lot of travel. Some patients might be fortunate in being able to receive home visits or check ups from a therapist.

1.2. Research Purpose and Rationale

The research reported in this thesis is an investigation of how to create a new medical tool to assist physiotherapists in treating stroke patients. The goal of the research is to explore how a new Virtual Reality (VR) tool increase the effectiveness of each therapist and their output while maintaining or increasing the quality of service provided to patients. This, in turn, may serve to offset the growing operational costs faced by healthcare organizations dealing with substantial increases in the aged population.

Studies show that there is potential in using VR for the rehabilitation of patients [40]. VR may allow for a wider range of support to be offered to each individual according to their needs. If successfully exploited, VR could substantially reduce the burden and cost of physical rehabilitation If only a one percent reduction in treatment cost could be achieved, New Zealand could save more than $1,000,000 a year.

A key attribute of VR is an ability to present to users virtual images of objects that are generated either by computers or video cameras. These images appear as ghosts of real objects, hence the title 'Ghost' project for this research. These virtual or ghost images can appear to originate anywhere relative to the user, even within their own bodies. VR can also provide a way for the therapist to interact intimately with the patient from a remote location and in real time. So one aspect of the Ghost project is to test if VR can provide an effective remote substitute for a face-to-face therapist but with equal or better efficacy.

The Ghost research and development is envisaged as being conducted in two phases: the first phase is the development of the Ghost technology; and the second phase is the evaluation of that technology in clinical trials. The purpose of this thesis is to address the first phase, that of developing and optimizing the technology in a non-clinical laboratory setting prior to later phases that will assess efficacy of this technology in formal field clinical experiments.

This thesis presents the design, develop, evaluate and tradeoff several hardware and software technologies and configurations that must be considered in this first phase of the Ghost research. These factors fall into two categories: 1) technology configurations with their hardware and software components; and 2) the usability of these technology configurations in addressing the needs of patients and therapists and their resulting outcomes. Although this thesis is focused on optimizing the rehabilitation technology configurations in a non-clinical or laboratory setting, we must still consider and be informed by the clinical application and projected use scenarios.

The hardware factors in the technology configuration include tracking and display components. The tracking component is the method by which the bodies and limbs of the users and/or therapists are tracked and monitored. Tracking is used to input the therapist's movements into software applications to instruct or direct a physical exercise or to measure whether a prescribed exercise is being performed correctly by the patient. The display component is the device that delivers instructional information through a visual or acoustic modality. For example, the display can be 2D or 3D, a virtual or real image display, head-mounted or panel-mounted displays. Different displays are likely to change how effectively and accurately a patient and therapist interact within the Ghost computer application. The combination of the tracking and display can be considered to be the 'medium' or delivery mechanism of the interface between the patient and therapist.

The software factors in the technology configuration generate the content or 'message' in the medium. This message consists of two parts: (1) representational/interaction constructs and (2) scenarios. The construct is the software that controls the content that the patient sees or hears through the display and the way that content moves or changes as a function of the interaction (e.g. movement) of the patient or therapist. The construct components also enable the method by which a user follows commands or instructions within the context of computer-mediated or therapist-mediated instruction with the patient. For example, does the therapist instruct movement of the patient by becoming a Ghost inside the patient (or egocentric view) as delivered by a virtual image via a head-mounted display or as an avatar by a real image presented on a panel-mounted display (exocentric view) outside the patient. Even these different constructs can have dramatic impacts on the efficacy of patient performance. Another construct is that of local or remote collaboration. The local construct provides the patent with a rehabilitation exercise that is generated locally by a computer; whereas the remote collaboration construct is a real time rehabilitation exercise instructed by a remote therapist in real time using telecommunication and telepresence technology. Here the patient and therapist can work together in real time. Each of these constructs may require different forms of display/tracking and feedback mechanisms to work successfully.

The second software factor is the scenario, or context of the interactive experience. For example, a game of catch or trying to swat a fly. Such a gamification scenario may be effective in ameliorating issues around motivation, depression and retention in doing the rehabilitation exercises. Games can make exercising fun while adapting to and monitoring the patient's progress within a therapy protocol.

Taken together, the display and tracking hardware, and the constructs and scenario software, constitute the independent variables in the design of the Ghost system.

Accordingly, the dependent variables in the Ghost system are its evaluation metrics, figures of merit or measures of goodness. Generally the goodness of a human interface system such as Ghost can be assessed in five categories: intuitiveness (i.e. how easy it is to learn or the slope of the learning curve); effectiveness (gets the task done); efficiency (gets the task done in a timely way with minimum expenditure of motor and cognitive resources); affordability (doesn't cost too much); and likeability (emotional impact). Given the nature of the Ghost application, there is the additional measure of adherence, or the propensity of the technology to allow conformance to a particular treatment protocol signaling the overall benefit to the patient. For the purpose of this thesis, these measures of goodness and merit are grouped into the term adherence, or the ability of the therapists and patients working together with the technology to affect positive patient outcomes.

In summary, the goal of this thesis is to optimize the design of the Ghost technology configuration including its the hardware and software factors in the laboratory setting of Phase 1 to achieve the likelihood of good adherence when tested in the clinical setting of Phase 2.

1.3. Thesis Summary

The remaining parts of this thesis are organized in the following manner:

Chapter 2: Background Research
Provides a review of the relevant literature, identifying existing applications of stroke treatments, VRR and Serious Games. Chapter 2 includes a review of tracking and display technologies.

Chapter 3: Design Methodology
Discusses the interface design methodology and acknowledges the relevant stakeholders. The sample test application focuses on reaching tasks for a stroke patient, providing an overview of patient performance for the therapist.

Chapter 4: Prototype Development
Describes the design process and development of a stroke template for rehabilitation and the adaption of various tracking and display technologies to be evaluated.

Chapter 5: Butterfly Stroke Game
Presents the game prototype that is used as a base for all experiment designs.

Chapter 6: Evaluation
Presents the experiment design and evaluation approached used in experiments conducted as part of this research project.

Chapter 7: Experiment 1: Tracking Evaluation
Presents the experimental design for the evaluation of the tracking prototype.

Chapter 8: Experiment 2: Display Evaluation
Presents the experimental design for the evaluation of the display prototype.

Chapter 9: Experiment 3: Adherence Evaluation
Presents the experimental design for the evaluation of the prototype.

Chapter 10: Experiment 4: Serious Game Evaluation
Presents the experimental design for the evaluation of the serious game prototype.

Chapter 11: Experiment 5: Online Evaluation
Presents the experimental design for the evaluation of the online prototype.

Chapter 12: Lessons Learnt
Presents a summary of the results gained from the experiments and discusses the implications of the research.

Chapter 13: Conclusion and Future Work
Provides a conclusion on the current research and presents further research for future investigation of Ghost.

2. Background

Prior research conducted from various different sources have influenced the design of the Ghost System. Notable areas are reviewed in this chapter, as follows:

1. **Stroke -** This section provides information regarding the cause and effects of a Stroke.
2. **Neuro-rehabilitation -** This section provides information about the current treatments related to brain injuries.
3. **Virtual Reality Rehabilitation -** This section provides information about Virtual Reality and its potential for medical applications.
4. **Equipment -** This sections provides information around tracking and display technologies that might be suitable for the creation of a new medical tool using virtual interface technologies.
5. **Serious Games and Gamification -** This sections provides information on turning an exercise or task into a serious game.
6. **Representational/Interaction Constructs -** This section provides information on how to coax a user to follow a set of movement commands or instructions.

2.1. Stroke

What is a Stroke
A stroke is a loss or leakage of blood flow in the brain that causes rapid death of brain cells [43]. As such there are two forms a stroke can take:

1. **Hemorrhagic Stroke -** This is caused by weakened or diseased blood vessels rupturing and causing blood to flow into brain destroying brain tissue.

2. **Ischemic Stroke -** This is caused by a blockage in the blood vessels that results in a lack of oxygen to brain tissue causing them to die.

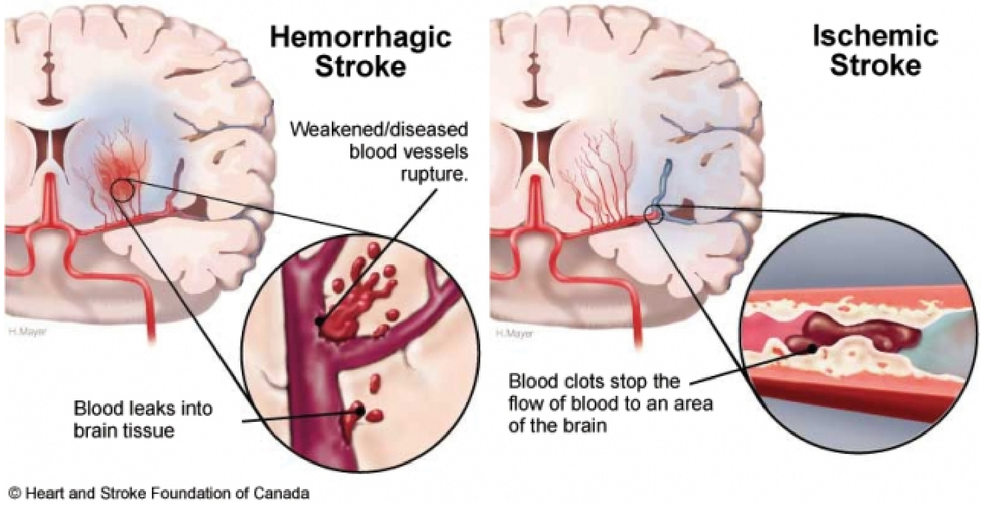


Figure 2.1: Types of Strokes, sourced from [1]

The larger the blood vessel that ruptures or blocked, the greater the extent of the brain damage done leading to a more severe stroke. The immediate treatment for a stroke at a hospital is to detect the type of stroke and then to unblock or seal the ruptured blood vessel. Brain cell changes happen in 2-3 hours after a stroke, with permanent cell death at 6-24 hours. With this in mind, treatment should be sought as soon as possible to lower the extent of brain damage.

Note: It is important to know the type of stroke a person has incurred before performing any treatment. The advice in the past was to give panadol to the stroke patient but this can have severe consequences. Panadol helps thin the blood cells moving through blood vessels, but if the type of stroke is a rupture, the result of administering would be an increase in blood flow into brain tissue resulting in more brain damage. Accordingly, the type of stroke should be determined at the hospital to identify the best treatment method before any therapy is administered.

How stroke affects the body
Stroke affects an individual in a number of ways and depends on a number of different factors. Factors that influence the effects experienced by an individual are:

1. **Brain Side -** Sections of the brain are allocated to different functions within the human body and the individual's cognitive processes. Depending on the location of the stroke, different functions are affected.

2. **Left Side -** A stroke on the left side of the brain affects the right side of the human body, resulting in:
    a) Paralysis on right side of the body
    b) Speech, and Language understanding
    c) Behaviour becomes slow, cautious
    d) Memory problems
3. **Right Side -** A stroke on the right side of the brain affects the left side of the human body, resulting in:
4. Paralysis on the left side of the body
5. Vision problems
6. Behaviour becomes quick, inquisitive
7. Memory problems

Severity of Stroke - The number of functions affected within an individual depend upon the extent of brain tissue that has been damaged. The amount of brain damage is directly proportional to the severity of the stroke. In some cases, this can result in both side of the brain being affected (Brain stem).

Other effects an individual might experience from a stroke are:

1. Loss of Motor Control
2. Loss of Balance
3. Loss of Speech
4. Cognitive abilities
5. Vision and Perception problems
6. Trouble swallowing
7. Bowel and bladder control
8. Mood swings
9. Depression

Mental Health
Besides the effects on an individual's physical health, mental health will also be affected to varying degrees. While depression is common and expected amongst stroke survivors, in some cases it can be so severe that the patient needs additional help and treatment. As a stroke is a health problem associated with brain damage, mood swings and other mental side effects can be experienced.

Brain Plasticity
It was originally thought that if a person had a stroke that nothing could be done for you as the brain could not learn/relearn past a certain age [44]; i.e. brain structure became fixed.

...as recently as 1960s the brain was widely believed to be "hard-wired" by the time a person was born and that structural damage thereafter was permanent and its consequences "incurable."[41]

Research conducted by Nudo [45] on squirrel monkeys shows how the brain adapts to deal with brain related injuries. Nudo mapped the brains of monkeys to see which part of the brain controlled which functions within the monkey's body. He would then induce a stroke on the monkey by damaging the part of the brain that controlled a specific motor or cognitive function he wanted to investigate. Nudo wanted to determine if there was brain plasticity in monkey that might signal ways of how to help human patients recover from stroke. As shown in Figure 2.2 below this was achieved by presenting food wells of different sizes to the monkeys while restricting which arm the monkey could use to obtain food. The results showed that monkeys can recover from small infarcts (cerebral infarction is a type of ischemic stroke resulting from a blockage in the blood vessels [46]) after about one month but large infarcts result in chronic impairment in motor skills for a more extended period. Monkeys also showed a preference to use the less-impaired limb when given the choice, even after 2+years after the stroke.

Figure 2.2: Monkey recovering from a stroke, sourced from [2]

Nudo emphasized the need for primate experiments because research done with rodent experimentation had lead to a mistake in neuroprotective drugs: a drug was found to help in the recovery of rodents but the difference between species was not taken into account for human trial, only the weight ratio was used. What is important, is that the Nudo research shows that undamaged parts of the brain can be remapped to regain lost motor control in monkeys and that likewise this is possible in humans depending on the severity of the stroke.

2.2. Neurorehabilitation Background

In this section we present a number of neurorehabilitation treatment types. Neurorehabilitation is a medical process to aid the recovery of an injury to the nervous system, by helping to compensate for any functional restrictions experienced as a result. The most common forms of nervous system damage are from injury to the spine or brain damage.

Action Observation Treatment
Action Observation Treatment (AOT) [47] exploits a neurophysiological mechanism for the recovery of motor impairment. In neurophysiology it is now established that the same neural structures that are used for carrying out an action are also triggered by observing the same action being performed, providing the person observing is familiar with that action. For example, a dancer watching another dancer perform a routine they have both practiced will trigger AOT but will not trigger the effects if the movements are unknown to them. AOT is used in medical treatment by having the patient observe an action, performed by an actor (this can be a recorded video), and then perform the same action. This method of approach reduces the rate of error in performing the action/task and increases the rate of recovery.

Figure 2.3: Action Observation Treatment,adapted from source [3]

Constraint-Induced Movement Therapy

Constraint-Induced Movement Therapy (CIMT) [48] is a method of forcing a patient to use their affected limb more by constraining the unaffected limb. This method can be used during training for several hours a day or constraining the unaffected limb for 90% of the patients waking hours. Such an approach leads to brain plasticity changes and reorganization of sensorimotor representations. This method has been used with both stroke survivors and children with cerebral palsy [47].

Figure 2.4: Constraint Therapy Treatment, sourced from [4]

Mirror Therapy

Mirror Therapy [49] uses a combination of visual and proprioceptive feedback to help a stroke patient in recovery. This method involves the use of a mirror that is placed in the mid-section of the patients chest. The mirror hides the affected limb and uses the reflected image of the unaffected limb as part of the treatment process. The mirror reflection creates the illusion that the users affected limb is now healthy. Exercises involve the patient opening and closing both hands at once and moving both arms around. The reflection helps trick the patient's brain into thinking the affected limb is now working properly. This method has been used successfully to relieve phantom pain in amputees and aids recovery of stroke survivors.

Figure 2.5: Mirror Box Treatment, sourced from [5]

Motor Imagery
Motor Imagery [47] has been linked to the same effects as action execution and observation (see AOT). This method of treatment requires the patient to imagine (i.e. rehearse in their mind) performing the desired task or action correctly before each attempt. This form of treatment produces positive results including an improvement in balance for the elderly and in the recovery of stroke survivors.

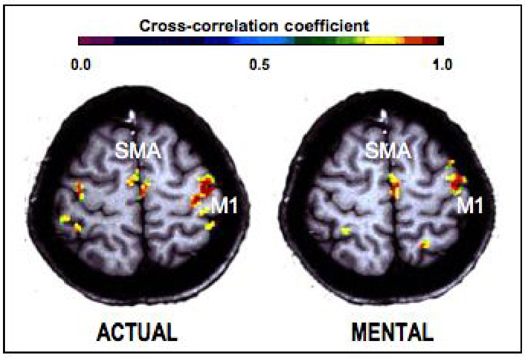


Figure 2.6: Motor Imagery Treatment, sourced from [6]

Translational Medicine
Translational Medicine [47] is not a form of medical treatment but rather a re-education approach to change the attitudes and perception of patients. This form of practice helps the patient work around the limitations of their current condition by using alternative means to complete tasks on a daily basis. For example, if patients are unable to paint with their hands, they can use their mouth instead. Through this method, the patient is shown how they can adjust their old methods of doing things to maintain lifestyle they to which they were accustomed.

Figure 2.7: Translational Medicine Treatment, sourced from [7]

Neuro-rehabilitation Summary
The treatments outlined above are currently being used by physiotherapists in helping stroke survivors and other patient types recover and adapt to their conditions. Some of these tools can be beneficial and used within the Ghost system. For example, we can use AOT to show the patient the needed exercise or task and guide them in their attempt. We can implement a version of Constraint therapy whereby we monitor which limb the patient is using to complete a task or exercise. We can also use technology to simulate Mirror therapy by tracking the patient's good limbs and changing the output displayed to simulate healthy limbs. Translational medicine techniques can be used to create tasks or instructions to help patient carrying out daily activities.

2.3. Virtual Reality Background

Virtual Reality (VR) technology creates a computer-generated interactive 3D world in which a user can experience sensory immersion. VR can be used for games, education, simulation, training, and in our case - rehabilitation. It is a tool that allows us to simulate real world conditions and enhance or alter them.

Virtual reality is implemented by using input and output transducers connected to a high performance computer that is running a software model or simulation of a virtual space or world. The output transducers provide visual, acoustic or tactile signals or stimulation to the sensory endorgans of the user in accordance with their position or activity in the virtual world. Simultaneously the input transducers monitor the movement behavior of the user and use that to adjust and manipulate the real time sensory experience being provided to the user.

The topic of virtual reality is extensive and an in depth review is beyond the scope of this thesis. However, there are there are the three aspects or saliencies of virtual reality or virtual interfaces that should be addressed that will affect the design of a stroke rehabilitation tool using VR.

Cybersickness Cybersickness is a motion sickness-like symptom that a user may experience from an immersive virtual environment [50]. This condition my present in the user when their brain receives conflicting input from different sensory modalities (primarily cue conflicts between visual and vestibular cues). For example, while viewing an immersive virtual environment via a Head Mounted Display (HMD), the user's eyes could be perceiving a translational or orientation movement in the virtual world that is dissimilar from the actual movement in the real world. This dissonance between sensory cues increases the likelihood of motion sickness in virtual space or cybersickness. The effects of cybersickness can range from nausea, vomiting, headache, somnolence, loss of balance, and altered hand-eye coordination. As we will be investigating the use of HMD as part of the Ghost project, cybersickness will need to be monitored carefully among participants.

Haptic Feedback Haptic feedback is used to simulate touch in a VR environment [51].It can be described as tactile feedback through the use of technology to recreate the sense of touch. It can be provided in a number of different ways, such as through the use of vibration devices. For example, the user presses a button on a controller to fire a virtual gun, the controller would then vibrate through the use of a vibration transducer as the virtual gun is being fired. Other ways of generating haptic feedback can be through the use of a robotic arm, such as the Phantom [52]. In this case a stylus pen held by the user is connected to the robotic arm that can then provide force feedback through 6-Degrees of Freedom (6-DOF). For a more realistic experience, a whole body exoskeleton is needed: this can be used to provide force feedback to the user as they move their body around.

Auditory Input Audio is often overlooked but has been found to provide a deep level of immersion if implemented correctly:

To move toward a more immersive virtual environment, one needs a display that can provide true 3-D stereo.[40]

Human beings are surprising very good at detecting the direction of sound; with an average error of 3 degrees in azimuth and 4 degrees in elevation to location of sound projection [53]. If 3D sound is included in a VR system, a more engaging experience can be created for the user. Sound can also be used as audio cues to guide a user through a set of tasks. In short, audio can be used to provide distance and direction of an event in a VR environment.

2.4. Virtual Reality Rehabilitation

Rehabilitation using Virtual Reality spans a number of different areas, from phobia treatment to post traumatic stress disorders and physical rehabilitation. For the purposes of this research we will focus on physical rehabilitation in VR combined with its effects on learning and motor control.

Based on research for VR Motor rehabilitation [40], we have found 3 key concepts for success:

1. **Repetition -** Repetition is important for rehabilitation. It is the act of repeating an exercise that produces successful results.
2. **Feedback -** Feedback about performance is important so patients can track their progress. If a serious game is used in a VR environment, patients will focus on the feedback and on successful completing a challenge such as gaining a high score. By drawing the patient's attention away from the exercise, we can provide a more enjoyable and better rehabilitation experience. Feedback has been researched and proven to increase the learning rate:
   Studies of feedback or knowledge of results (KR) show it to be the strongest, most important variable controlling performance and learning.[54].
3. **Motivation -** Without motivation the patient will not want to continue the rehabilitation and/or struggle with exercises.

The following subsections will go into more details about some of the different areas involved in VR rehabilitation.

Virtual Reality Training vs Real World Training
Real World Training may be perceived as being a better option over VR Training due to the fact that a human expert is providing the training and not a computer system. There is also the reduction in cost for not needing the necessary equipment for VR system. Advantages of VR however, are the following:

1. **Sustaining -** Can be self sustaining once training has been provided on how to use the equipment.
2. **Task Assistance -** Can make tasks easier by highlighting and augmenting the VR world in a way that cannot be achieved in the real world.
3. **Less Dangerous -** Can be less dangerous. For example, fire fighting training.

4. **Customization -** Can customize the VR environment to suit the users needs.
5. **Enjoyment -** Can provide a greater level of enjoyment through gamification.
6. **Increased Learning -** Can be a greater learning experience for users through feedback.

There have been limited papers that compare learning in VR to learning in the real world[40]. However, one study addresses rehabilitation through virtual and real table tennis[55]. The study involved three user groups: (1) Users trained in VR, (2) Users trained by expert, and (3) Users self taught. The groups were each given a period of time for training before a final performance test was held in the real world. The results showed that the user group that trained in VR performed better than the other two groups in the study. This shows the potential of VR in not only filling the gap created by the lack of experts, but also the potential for it to offer a better learning experience than the real world to the users.

Virtual Reality Learning

Learning via VR has been shown to be effective. One reason is that users can receive real time feedback in tasks performed in a virtual world that would be difficult in the real world. For example, users can detect and correct errors they make faster through augmentation and feedback [40]. Users can also learn through imitating the VR teacher in the VR world as this is a form of action-observation-treatment (AOT) [40] which triggers neural responses in the users brains. Users can also increase their learning rate through the use of trajectory or animations [56].

VR also allows the manipulation of a wide range of factors that might not be possible in the real world [40]. These factors can include: (1) Automatic training schedules, (2) Testing, and (3) Recording participant's motor responses. VR might also be an effective way of training a set of basic functions that, in turn. allow for a wider range of more skilled movements. This is especially true for training motor control for stroke survivors. One study involved users learning a set of VR motor movements and at the end of the study being tested on real world applications. The results of the study showed that the users not only performed well in the movements trained in the VR world but were also able to carry out a series of other tasks that they were not trained in [40].

Transferring Virtual Reality Learning to Real World

Based on current research there is evidence to suggest that for motor learning in VR, there is a transfer to the real world [40]. One study involved training the users in guiding a metal ring along a curved wire. If the ring touched the wire the user would fail the task. The results found that users who trained in the real and VR world performed well in the task when tested at the end of the study but when groups were tested on multitasking, the results showed that the VR group was more efficient and better equipped to handle the situation [57].

Another study [58] involved training a user on how to navigate the real world through a number of different routes to a destination. The user was also trained in a VR world in addition to the real world. The results not only indicated that the user was able to successfully navigate the real world through use of VR training, but was also able to recall the VR route a lot easier than the training received for the real world route. Another study for helping stroke survivors to walk showed that the VR group performed a significantly better than the group receiving real world training [59].

Motor Relearning
Motor Relearning is the process of doing a series of movements/exercises to encourage healthy parts of the brain to take on the role that belonged to other parts of the brain that are now dead; it is essentially the art of motor retraining.

One study for motor relearning involved chronic stroke patients learning how to avoid obstacles while walking [59]. One group was taught by stepping over foam objects, set at their stride length. The second group was taught by walking on a treadmill and stepping over virtual objects while wearing a HMD. While the study showed improvement in both groups, the VR group showed greater improvement during the fast paced test.

Motor Learning
Motor Learning is defined as a permanent change in motor performance. Motor performance is something that can be observed during a treatment but not motor learning; that is, a patient could perform well on one day and bad on another. Motor learning is when either the minimum or consistency of their performance has improved. In this regard motor learning is assessed via a separate test than that is used to train the individual.

Current methods of motor rehabilitation focus on repetition to encourage motor learning. But studies done on rats and monkeys have revealed that repetition alone is not enough. To encourage motor learning, there needs to be skilled movements of the limbs [60]. Studies also indicate that the motor cortex may play an important role as adjacent healthy cortex take on the new roles once belonging to the now dead cortex.

One review paper for "Virtual Environment for Motor Rehabilitation" states the following [40]:

"...scientific evidence suggest that augmented feedback about performance will

enhance the cortical changes associated with motor learning"

This paper also highlights that VR is not a treatment in itself but rather a tool that can be effective for rehabilitation. The paper then highlights the necessary components/background knowledge for a successful VR rehabilitation application. These are:

1. **Motor Learning -** Scientific rationale behind it.
2. **Motor Impairments -** Specific details presented by clinical populations.
3. **Engineering -** Understanding the capabilities of different software and hardware solutions and how to implement them.

The earlier research highlights the need for a diverse team, including clinicians, engineers, and neuroscientists.

Spatial Memory
Spatial Memory refers to the part of the memory used to record information about one's physical environment [61]. STwo studies using VR for probing spatial memory, are outlined below.

The first study was done on two groups of stroke patients. The first group was allowed to navigate through a virtual bungalow with four rooms. While they were navigating the virtual environment, they were told to spot 20 virtual objects. The second group was not allowed navigate but instead watched a video recording of one patient from the first group navigating the virtual bungalow. The results showed that the active VR group's performance was greater than passive VR use. One suggestion was to use motor encoding to increase spatial memory by using procedural memory [62].

Two studies involved the use of children with motor disabilities[61, 63]. In both studies the researchers note that cognitive maps or spatial awareness was lower among disabled-bodied children when compared to able-bodied children. They posit that the reason for this is due to the spatial exploration that able bodied children are able to experience. This helps them develop a cognitive map of their surrounds such as referencing locations from landmarks. Children with disabilities rely on others to help them in daily activities which in turn restricts their development in this area. The researchers wanted to see if Virtual Environments could be used to help improve spatial awareness. The results of the studies showed that not only did the children gain a substantial degree of spatial competence in the virtual environment but they were able to successfully navigate buildings and environments that were simulated. This finding shows that learning in a virtual environment also transfers to the real world.

Diagnostic Tool

VR has been shown in some studies to be of benefit in diagnosing and assessing patients. One study on evaluation and rehabilitation of motor deficits showed that their gaming system was able to measure reach distance and speed of the patients arm [64]. This allowed quantification of the patients motor deficits. Their system required the user to wear colour patches on their wrists and elbows which are tracked with the use of a motion camera. There were also data gloves for gathering data on finger flexion and dots on the physical table used to act as reference points for the patients.

Other research on telerehabilitation as a diagnostic tool could determine if a patient needed to visit a rehabilitation center [65]. This research involved the use of an accelerometer-based tilt center for testing stroke patient balance. The results of the research showed the potential of the tool in combination with virtual-reality supported balance training for remote evaluation. The researchers concluded that the tool may reduce the number of outpatient visit and enable effective rehabilitation at home but a further in depth study is required to verify this.

Another study in Texas involved VR as a diagnostic tool for testing patients *"active daily living"* following *"acute brain injury"*. The patient's task was to create soup and a sandwich in a virtual kitchen. Results of the study showed the viability of such an approach with significant results being found for the virtual kitchen performance [66].

Evaluation Tool

Likewise VR also has the potential as an Evaluation Tool. It can monitor a patient's progress and performance during rehabilitation exercises that can then be provided to the health care providers. One study involved the use of a scoring algorithm that allowed a therapist to specify different weights (changing of settings) for different patients. This is useful considering that most likely each patient will be different and develop/recover at a different pace. The types of settings or weights that could be altered by the therapist were:

- Displacement Error
- Orientation Error
- Angular or linear velocity
- Smoothness

All of these settings will change the difficulty of the rehabilitation for the patient. So when their condition is chronic and in the early stages of rehabilitation, the difficulty can be set too easy. As patients progress the therapist can make the VR treatment more difficult [67]. Throughout the patient's use of the VR system, results are gathered and interpreted by the therapist about the recovery rate of the patient.

Another study involved the use of VR to evaluate the condition of Parkinson Disease patients [68]. The study involved six tasks in the VR condition followed by neuropsychological assessment. The tasks included: walking, pointing to objects, speed and orientation, starting hesitation, incidental memory task. Two PD patients were tested alongside 10 healthy individuals. The results of the study showed that VR can be used as a tool to support traditional clinical tests for detection. It can also help teach patients on how to approach their disabilities.

Functional Tasks

VR can also assist in helping patients in their day-to-day activities. In one study patients with Parkinson's disease found that VR helped them overcome issues with walking, a condition termed kinesia paradoxa [69]. The study used a HMD to display virtual cues that the patient would step over thereby helping them move forward. Results of the study showed that to be successful,the following design requirement need to be met:

1. Ample vertical field of view.
2. Spatial Stabilization of images.
3. Near cue and far cues: between 2-3 cues placed 2-3 paces ahead.
4. The greater the impairment, the more interactive and realistic the cues need to be.

The near cue is important as it initializes the person to walk or step over the object. The far cues are used to stimulate continued movement. The interactive realism is linked to the person's condition. So if the person's condition is severe, the cues need to more be realistic or similar to their normal walking speed and stride length.

Simulators

VR can be used to simulate the real environment in tasks that could potentially cause harm to the user. One study involved training stroke patients to safely use a wheelchair to avoid obstacle collision [70]. Obstacle collision among stroke patient happens due to unilateral or visual neglect: the patient does not process or ignores what the eye on the stroke affected side sees, resulting in collisions with objects on that (the injury) side. The study involved a control group and testing group of 20 participants each. The results of the study showed that VR is effective in training patients and improved visual neglect and reduced obstacle collisions. In a real world test the VR group collided an average of 1.3 times vs 5.1 from the control group.

Another research group performed a variety of studies on the use of VR for injury prevention, disability awareness, and rehabilitation in neurology [71]. But an interesting research project conducted by the group was on VR to teach children how to cross the street safely [72]. The research reported that 60-70% of children injuries under the age of 10 are from crossing intersections incorrectly or dashing out from the street between intersection. The study involved 95 children from suburban and urban school divided roughly in half. One group received the VR pedestrian safety intervention while the other group received an unrelated VR program. The children were then tested in the real world with observers monitoring them 1 week before and after the training. Results showed there was a transfer of learning from the Virtual to Real World but only for the suburban children. The researchers suggest that transfer is possible for urban children with more training and suggest an approach on how to educate children in crossing the road safely.

Balance Training
Stroke patients can suffer from a loss of balance. VR has been shown to help patients recover from an imbalance/vestibular disorder. One study previously cited on wheelchair training for stroke patients [70], not only improved visual neglect and obstacle avoidance, but it also reduced the number of falls patients had in the hospital during inpatient stay: 2 patients fell in the VR group compared to 8 in the untrained patient group.

A study on vestibular rehabilitation using VR [ref 107, pg 205] noted that patients with this condition are more likely to suffer a fall and injure themselves. The current treatment for this disorder is to expose the patient to increasing levels of stimuli in order to promote habituation. In physical rehabilitation this approach be challenging in both avoiding harm the patient while exercising good judgement when increasing the challenge or difficulty of the patient's therapy. The researchers used a new device they have invented called balance near automatic virtual environment (BNAVE). The study had participants stand while viewing a sinusoidal waveform on a form plate. Results indicate that young and old people with and without vestibular disorders exhibit a postural sway as affected by a visual scene in movement while in an immersive virtual world. The researchers showed that VR is a potential tool in safely helping patients recover through increasingly challenging environments in a safe and controlled setting.

Another study showed how VR can affect the postures of individuals by changing their perception within a CAVE [55]. The researchers used healthy individuals and found that there may be limits of motion placed on each body segment from postural controls rather than visual signal: the upper body would respond to visual changes from the hip while ankle movements were linked to ground inputs and segmental proprioceptive inputs. Investigators also found that participants would shorten their step and increase ankle flexion to increase their awareness on sensory signals and motor output. This locomotor pattern is similar to that of the gait displayed by elderly people who had fallen.

Telerehabilitation
Overall, there seems to be a need for telerehabilitation with patients with immobility and living in remote/rural areas with restricted or difficult access to direct service. A review on Virtual Environments for Motor Rehabilitation [40] shows a trend in VR systems starting to support telerehabilitation in some form and mentions significant improvements that were seen in some systems. Another review on Virtual Rehabilitation and Telerehabilitation for Upper Limb [73], notes the feasibility of such systems but it is unclear how effective they are due to conflicting results received from the reviewed studies.

Stroke
The review paper done on Virtual Rehabilitation and Telerehabilitation for Upper Limb [73], states that more than 80% of stroke patients suffer from unilateral sensor motor deficit and that stroke is the most common cause of chronic disabilities of elderly patients in upper limb functionality. The researchers also state that only 5-30% of stroke patients fully recover function of their upper limb with a further 25-37% attaining good use. Walking seems to be easier for stroke patients with 70-95% being able to walk again. As recovery of stroke slows down after 6 months, with upper limb taking the longest to recover, a stroke patient can benefit from rehabilitation several years after a stroke. The researchers also highlight that nonimmersive strategies are more suitable for elderly stroke patients.

The review on Virtual Environments for Motor Rehabilitation [40] provides an extensive source of information for VR in rehabilitation. It includes various subsections that are beneficial to the work VR has done in this area, among which is the use of VR for stroke rehabilitation. What was interesting is that the researcher found that patients are capable of learning in VR. Furthermore, motor skills learnt in the VR transferred over to real world equivalents and in some cases, secondary motor tasks were learnt in VR from performing the main motor tasks. The researcher also notes that VR is not a treatment in itself but rather a new technological tool that can be used to enhance motor retraining. The success of the tool depends entirely on how it is implemented.

1. Scientific rationale behind motor learning.

2. Details of motor impairments.
3. Engineering knowledge of potential capabilities of various technologies.

Problems
While VR shows a lot of potential and has its strengths, there are limitations that should be taken into account. One reference [36] highlights these potential limitations of VR technology that require improvements:

"Limitations of VR might result in a decreased sense of presence due to heavy and cumbersome headsets, low spatial resolution, narrow field of view that may presently be available in the headsets, primitive methods of force and tactile feedback, inappropriate time lags in tracking performance, induction of stimulator/motion sickness/cyber sickness"

TThe researcher also states that there are two forms of VR: immersive and nonimmersive. Technology such as the Nintendo Wii might be the best approach for rehabilitation while issues in VR technological and cost are addressed. The following diagram from [36] shows the limitation of VR in rehabilitation:

VR Application	Benefits	Challenges
Neuro-muscular	• Improve compliance • Fine time resolution • Rehabilitation at home • On-line data gathering	• Equipment cost • Technical expertise • Safety at home • Network bandwidth
Post-stroke	• Engaging/motivation • Repetitive intensive • Adaptable to patient education • Usable in chronic phase • Activities of daily living	• Clinical acceptance • Technical expertise • Abnormal limb configuration • Upper functional population applicability • Cognitive load
Cognitive functions	• More realistic assessment • Reduced therapy cost • Increased safety • Learning transfer	• Equipment cost • Safety at home • Psychological factor

Table 2.1: Benefits and Challenges of VR, sourced from [36]

2.5. Equipment

In this section we outline technologies that could be integrated to create a new tool for rehabilitation medicine. The section has two main components:

1. **Tracking -** This is the input from the patient into the system.
2. **Display -** This provides feedback to the patient from the system.

2.5.1. Motion Tracking

Motion Tracking can be used to monitor movement or simulate movement in a virtual world. The tracking can come in a number of different forms and from a number of different devices, ranging from infrared tracking cameras to electromagnetic tracking devices.

- **Infrared and Camera Tracking Systems** work well but require line of sight of the user or tracking markers to the cameras doing the tracking. If and object obscures a user or tracking marker then tracking is lost.
- **Electromagnetic Tracking Systems** do not require a line of sight like Infrared and Camera Tracking Systems. The disadvantage however is the tracking can suffer from interference from large metal objects and from electromagnetic fields generated by electronic devices.

Infrared Tracking Systems

1. **ART Infrared tracking**
   ART infrared tracking system [74] used in the HIT Lab NZ allows for 6-Degree-Of-Freedom (6-DOF) tracking through the use of predefined tracking markers that reflect infrared light. The predefined markers contain special reflective material that reflects the infrared light to a higher level than surrounding objects.

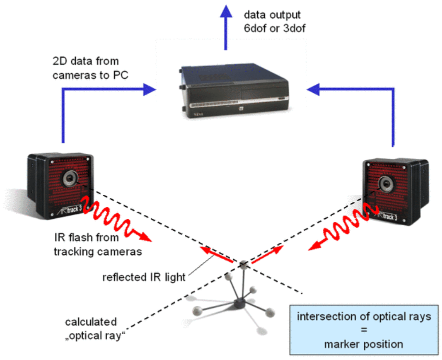


Figure 2.8: ART Tracking System, sourced from [8]

2. **Kinect 1 and Kinect 2**
   The Kinect V1 is a low cost motion capture device created by Microsoft [34]. Originally it was designed for use with Microsoft's Xbox as an alternative means of control after witnessing the success of the Nintendo Wii. However the worldwide community saw the benefit of using the Kinect in other systems and applications. In this way the Kinect has become one of the most popular and cost effective tracking solutions to date.

   The device works through the use of an infrared camera that creates a point cloud of its surrounding. From this point cloud the Kinect SDK is then able to process information about the user. This information can range from the users location relative to the Kinect, to information about the location of their limbs and joints (Skeleton Data). The Kinect can track the location of up to 6 people in a room but only return Skeleton Data for two users. The ability to track the limbs of a user makes it very useful for rehabilitation applications and training simulators. The Kinect V1 does provide 6-DOF but requires line of sight for each of the limbs to be able to track it in 6-DOF.

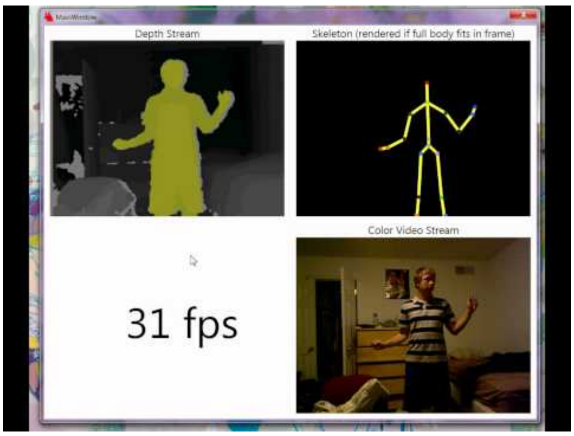


Figure 2.9: Kinect Version 1 Tracking System, sourced from [9]

Microsoft is also released a second version of the Kinect V1, called Kinect V2. The Kinect V2 will offer more reliable tracking than the original Kinect V1 and also a wider range of user analysis [75], including be able to measure:

a) heart rate,

b) muscle conditions,

c) muscle force,

d) joint rotation, and

e) hand grasps.

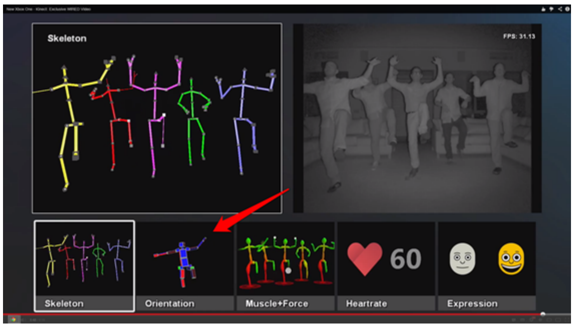


Figure 2.10: Kinect Version 2 Tracking System, sourced from [10]

3. **Nintendo Wii Remote**
The Wii Remote is a 6-DOF controller created by Nintendo [76]. The Nintendo Wii itself was less powerful than the current market competitors - Xbox and Playstation, but due to the unique nature of the system it was a huge success. The success came from the simplicity of the way you interact with Wii games. If you were playing a baseball game you would simply swing the controller/remote as the virtual ball got within striking distance on the screen. This form of user experience allowed people of all ages and disabilities to play. This was not possible, or at least extremely difficult, compared to other console controllers which were for gamers.

The Wii Remote has been seen as a useful tool for rehabilitation as well as games for health. The Wii Remote works through the use of a number of different sensors: accelerometer (for speed), infrared camera(for tracking), gyro sensor(for balance). Nintendo even created add-on controls for the Wii Remote as well as a Wii board for an additional method of control.

(a) Wii Remote (b) Wii Fit

Figure 2.11: Wii System, sourced from [11, 12]

4. **Playstation Move**
   The Playstation Move [77] was released for the Playstation3 game console and is Sony's version of the Nintendo Wii Remote [77]. It provide the 6-DOF tracking to allow the user to interact in 3 dimensional (3D) space within a virtual world.

Figure 2.12: Playstation Move System, sourced from [13]

Camera Tracking
Kinect V1 and V2 have the ability to act as camera tracking devices due to their ability to detect RGB values along with computer vision based approaches.

1. **Playstation EyeToy**
   The Playstation EyeToy was released for the Playstation 2 [78]. It is a simple video camera that is used as a motion capture device. This allowed users to interact with games through the use of their bodies. Users were only able to interact in 2 two dimensions (2D) with Playstation 2 games due to the nature of the technology being used: standard video camera cannot provide depth information about a user.

Figure 2.13: Playstation EyeToy, sourced from [14]

Magnetic Tracking

1. **Flock of Birds** The Ascension Flock of Birds is an electromagnetic tracking system created by the Ascension company [15]. It works by placing magnetic tracking components onto objects or parts of a users body that you want to track. Each tracking component contains a cable that is connected to the flock of birds tracking box which measures distance and orientation from the world origin box. The tracking box is used to process all the information about the state of each tracking component. This system does allow for 6-DOF but like all electromagnetic tracking systems, can suffer from interference from other objects.

Figure 2.14: Ascension Flock of Birds Tracking System, sourced from [15]

2. **Razor Hydra** The Razor Hydra is an electromagnetic device created by the Razor company [16]. It allows for 6-DOF tracking through two hand held controllers that are connected to an electromagnetic tracking ball. Each controller also contains a number of different inputs: analog stick(for movement in the VR world), and buttons.

Figure 2.15: Razer Hydra Controller, sourced from [16]

2.6. Display Systems

2D Display System
2D Display Systems involves the use of either a TV, computer monitor or projector. This type of display is the most common for VR, for the following reasons:

1. **Cost -** 2D display systems are a lot cheaper than 3D display systems.
2. **Ease of Use -** 2D display systems are easier to setup and use for virtual environments.
3. **Cybersickness not a problem -** To date there has been no reports of cyber- sickness when using 2D systems. This is ideal when with patients who could be affected more than healthy individuals.
4. **Collaboration -** 2D systems allow all participants to see the same state of the virtual environment at the same time. This is useful when a therapist is using VR for patient rehabilitation: the therapist can instruct the patient in the desired task while they both view the same scene at the same time.

Figure 2.16: Wide Screen TV, sourced from[17]

Head-Mounted-Displays(HMD)
HMD's are designed to be worn over the users eyes and provide a 3D stereo view of immersive graphics. Research using HMDs for therapy has been done in the past with varying degrees of success. One of the main problems with past research conducted was the limited field of view from the HMD's. With the invention of the Oculus Rift [79] this issue may be overcome. The Rift increase the FOV from 30-45 degrees to a 90 degrees field of view. There are also other companies releasing their own HMD configurations to compete with the Oculus Rift. The use of new HMD technology may provide more significant results in VR therapy compared to the past.

Figure 2.17: Emagin Z800 HMD, sourced from[18]

Oculus Rift
Oculus Rift is a HMD that provides a greater field of view than previous HMDs. This wider field of view creates a greater sense of immersion in a virtual world. Humans have an instantaneous a field of view of around 180 degrees horizontal by 90 degrees vertical, but 90 degrees horizontal with high resolution seems to be enough to engage users in a sense of immersion. Oculus is a relatively new product with only a developer kit available: the commercial product has yet to be released. However, there is a second developer kit coming out soon that offers a low

persistent screen. This should reduce eye strain and provide a more realistic experience to the users.

Figure 2.18: Oculus Rift Developer Kit 2, sourced from[19]

VisionSpace Passive Stereoscopic
The HIT Lab NZ's VisionSpace[80] is an immersive 3D theatre composed of 3 large display screens, 3 large mirrors and 6 projectors. Each screen is connected to one large mirror and 2 projectors. The mirror is used to reduce the throw distance necessary for the projectors to work. By having the projectors project towards the mirror, the distance can be doubled which in turns leads to a larger image being projected on the 3 large screens. Two projectors are used for each screen to represent left and right eye of the user. Each projector contains a circular polarizer filter that when viewed through similarly polarized spectacles, removes the image connected to the opposite eye. The two projected images for each screen to each eye is combined in the users visual system to produce a binocular a sense of depth. This type of 3D system is passive, therefore it does not have the same eye strain that people experience from flicker displays, such as the Nintendo 3DS [81].

Figure 2.19: Vision Space Theatre, sourced from[20]

3D TV
3D TVs [82] have started to become commercially available within the last few years. These displays do offer a more engaging experience that traditional 2D displays. Due to it being a relative new technology, research in this area is limited when looking at Rehabilitation.

Figure 2.20: 3D TV, sourced from[21]

2.7. Serious Games

A lot of the research reviewed in this chapter on VR involves the use of serious games as part of their system for rehabilitation. Games are becoming an essential component in VR rehabilitation since they can motivate and engage patients. Patients often enjoy their time in VR rehabilitation exercises(games) and tend to spend longer times in any given session when compared to traditional rehabilitation methods. There are some components involved in making a successful serious game which are outlined in the following sections:

Off the shelf games
There has been a surge in rehabilitation and exercise games in the healthcare sector in the last few years. According to a review paper on Games for Health [22], the reason could be due to the creation of new technology that allows interaction between a users body and the game (Wii remote, Kinect V1, see section 2.5 for further information). It was shown that 59.7% of health game studies reviewed used off the shelf commercial games and that the keyboard and mouse were the main haptic interfaces 45.6%. It was also shown that computer based games composed of 67.8% and console games 31.5% of the systems used. The figure below shows the wide range of areas in the healthcare sector that use these games.

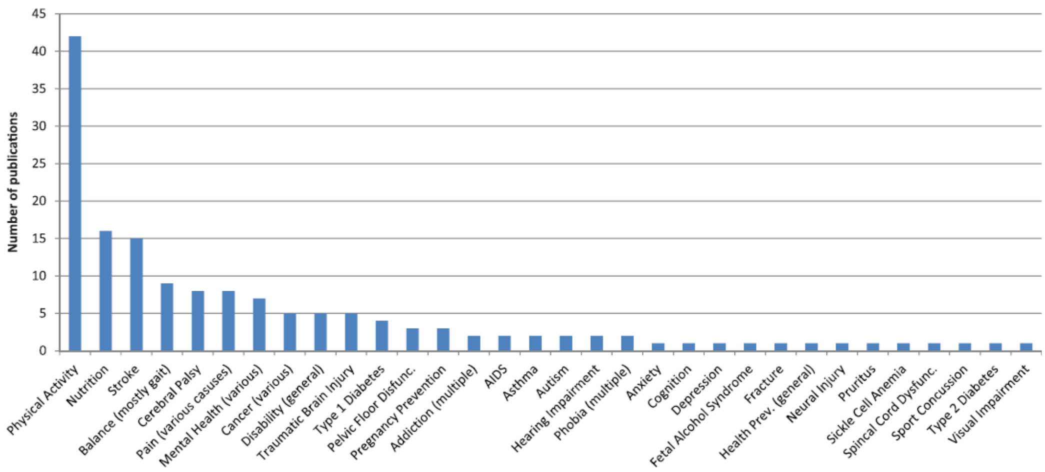


Figure 2.21: Tables on Games for Health, source from [22]

The researchers highlight the reason for the use of commercial games in the healthcare sector is due to their advancement in gaming technology and lower cost compared to custom-made computer games. The disadvantage however, is that commercial games lack customizability for patients that custom-made games offer.

One study on Parkinson Disease used the game Dance Dance Revolution with a dance mat [23] for four treatment types: cognitive movement strategies, physical capacity, balance training, and cueing. Besides the treatment component, the researchers also highlighted that interactive videos games can increase the likelihood of adherence to physical activity due to the enjoyment the patients get from playing the games. Apathy may be overcome through rewarding stimuli provide by the game which in turn can trigger 80% of dopamine neurons in the brain from this reward based approach. Dopamine may result in improved motor performance as PD is a condition suffering from dopaminergic deficiency.

Figure 2.22: Dance Dance Revolution, source from [23]

Gamification

Gamification is the method of turning a task/exercise into a serious game. It involves understanding what are the key points or purpose of the task/exercise and then implementing those points in a game. One example is on research conducted on stroke reaching exercises with the use of Kinect V1 in a serious game called "Punching Duck" [24]. It uses the kinect and gamification to encourage its users to achieve a higher level of repetition with reaching tasks. The game involved targets that would popup in a manner similar to a shooting gallery. Patients would control a 3D arm on the screen with their impaired arm and were required to punch/touch each of the targets with the 3D arm. The 3D arm had an algorithm, and required calibration prior to the game, which gave the illusion that the patient's arm was healthy by having the 3D arm move in a natural way on the screen. Patients saw the game as fun/challenging compared to traditional methods of doing reaching tasks. When one patient was asked if they would like to take a break when having difficulties with one exercise. The patient responded:

"Take a break? No, I don't need a break; I'm just getting warmed up."

The authors highlight how uncommon it is for patients to be motivated to perform over a 100 reaches a session. This shows the potential of VR therapy in retention and motivation that is not seen in conventional therapy with having patients push through frustration and fatigue.

Figure 2.23: Duck Duck Punch, source from [24]

Artwork
As modern pc and console games continue to push the boundaries of artwork to ever higher levels, there is a reflection on serious games to meet some of the standards placed by these games. One research project conducted on Parkinson Disease (PD) looked into the process of design and creating a serious game [25]. The game involved the patient controlling a 3D avatar with the use of Kinect V1. The gameplay was to collect various objects while avoiding others, this was done by navigating a platform the avatar was standing on closer to the object and reaching out with their hand to collect them. The platform was controlled by having the patient step forward, back, left, right to move the platform in that direction. On more difficult levels, the patient was required to collect certain objects with a certain hand. A workshop was held with 2 PD patients and a caretaker in helping to design the serious game by reviewing commercial products. A study was then conducted with the created game on 9 PD patients. The aim of the study was to see if exercise games with the use of Kinect V1 are feasible and safe in a home environment. The results of the study are were positive with the Kinect V1 deemed safe and feasible for people with PD. What was interesting in this research was the patients response to some of the questions asked. When asked if they would purchase the game if available to buy, most of the patients were hesitant with either an outright no or unsure due to unknown cost involved. One patient commented:

"I think it has great potential but needs refinement. The graphics look dated and the style childish."

The patient also remarked that the grandchildren would not be interested in playing with him when asked he if would like to play the game with other people.

In other questions there was a problem with depth perception and object identification (birds and wasps being hard to judge). Overall the research provides a good template in designing a serious game, with patient comments providing rich data on good and bad aspects of the game. However it does highlight that patient expect the same quality that exists in commercial games in serious games.

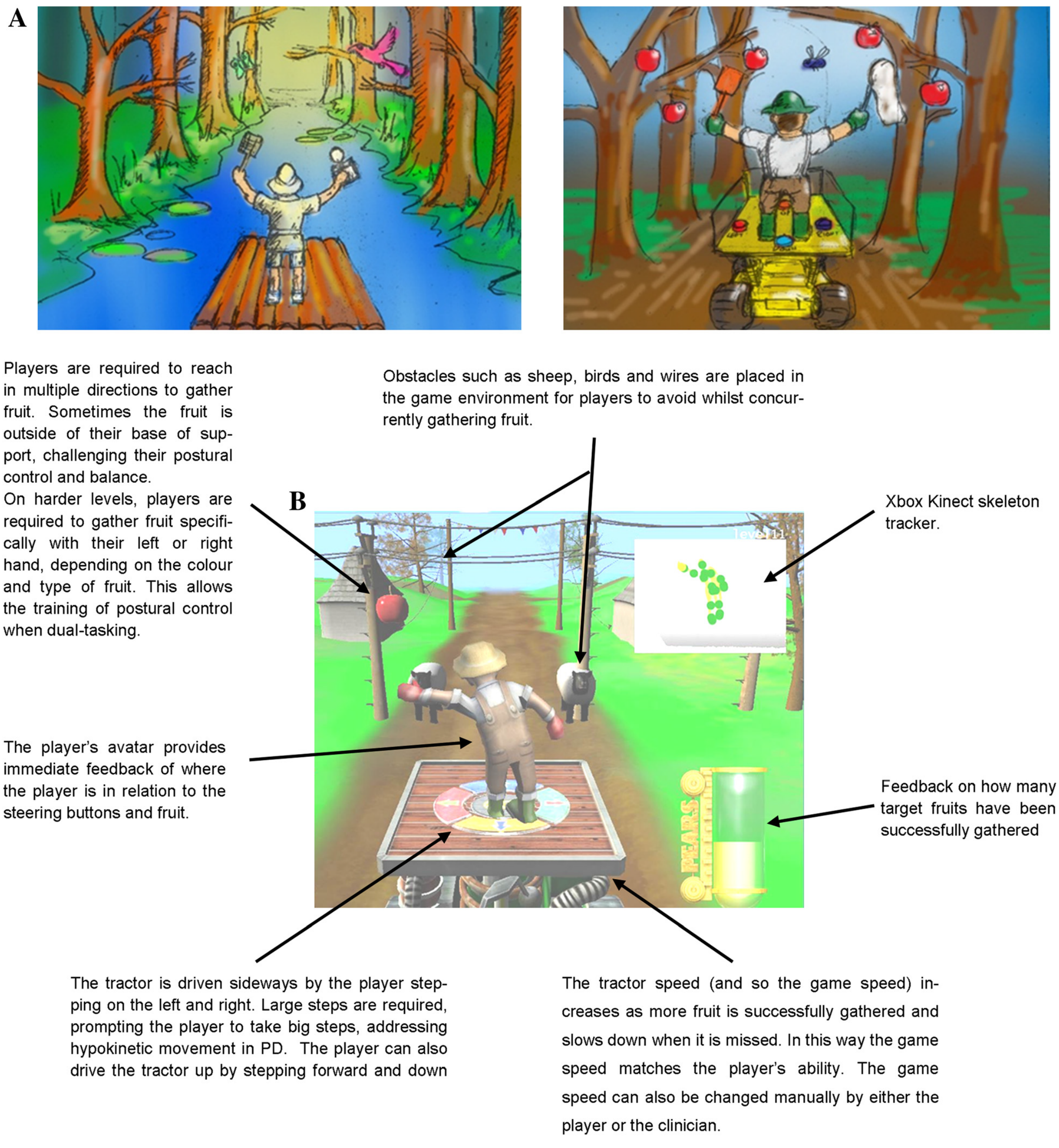


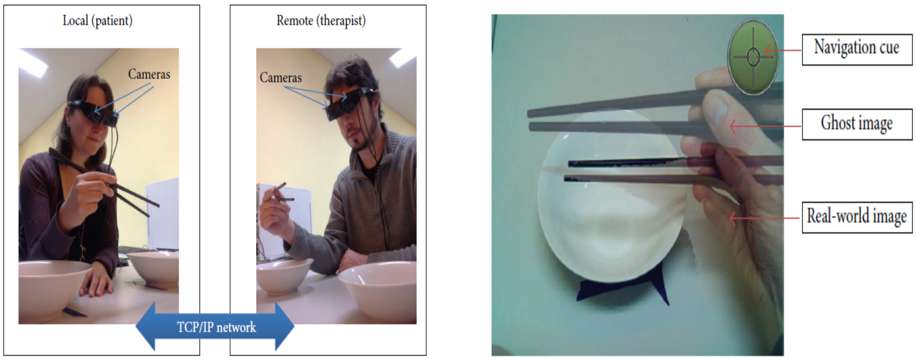
Figure 2.24: Parkinson Disease Reach Game, source from [25]

2.8. Representational/Interaction Constructs

Having the patient perform the exercise/task correctly can be difficult. The person who has suffered a stroke is likely to have limited flexibility in their limbs and have a tendency to do compensating movements when performing a task: having their arm at strange angles when picking up an object as it is easier for them compared to how they use to pick up objects before the stroke, which is now difficult. VR and serious games can help the patient perform the necessary steps required in a task/exercise while reducing frustration and providing clear feedback on performance.

One research project created a VR haptic device called Rutgers Ankle to help stroke patients in ankle control [83]. The patients were required to navigate an aeroplane through a series of square hoops and were scored on accuracy by hoops collected and missed. Difficulty could be increased by location and number of hoops, aeroplane speed, and amount of force feedback provide through Rutgers Ankle. A second version was also created with a speed boat by having the patient avoid hitting buoys. A pilot study was conducted with the aeroplane game. It involved a single patient and showed improvements in accuracy: 32-95%, and the time required to climb a set of stairs: 90-20 seconds by sessions 1-6. It was noted by the researchers that the patient was receiving physical therapy alongside VR rehabilitation so it is difficult to separate what contributed to their recovery more. Two more studies were also conducted with the Rutgers Ankle: stroke patients in study one [84], and orthopedic patients in study two [85]. Results have shown improvement in patient conditions with future work being conducted to simulate different conditions on the feet to assist in walking: ice, gravel, sidewalk.

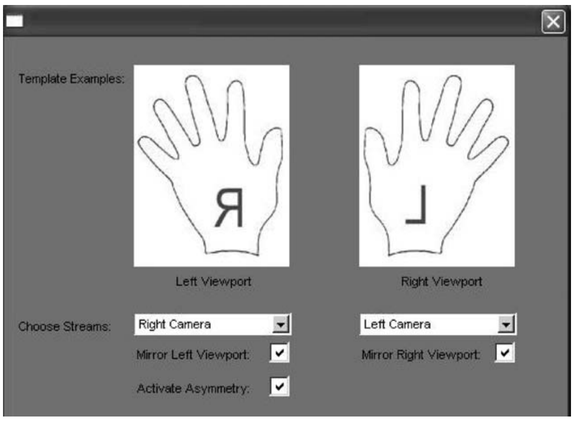
Ghostman Ghostman is a research project with a similar concept to Ghost [26]. “Ghostman is a wearable visual augmentation system in egocentric view through which users can observe their own movement being overlaid with a “ghost” image of the instructors body in real time”. The researchers go on to say that Ghostman uses an AR approach so that the real world is still viewed by the user. Ghostman uses two computer systems linked together over a network. Each system has a HMD with a video camera located on the front of the HMD where the eye would be. A study was done to see whether Ghostman was comparable to face-to-face training. The experiment design involved training a user in how to use chopsticks with retention tested at 1 and 7 day intervals. The results of the study found that Ghostman was comparable to face-to-face training and that its shows potential for other areas of application: rehabilitation and teaching patients to learn or relearn motor skills. The researchers did note that the system was expensive at $3,000.00 and may not be suitable for individual home rehabilitation but rather the system could be setup in a remote healthcare facility that patients had access to.



(a) Ghostman Collaboration (b) Ghostman View

Figure 2.25: Ghostman, source from [26]

Augmented Mirror Box One interesting approach for rehabilitation is the work on combining mirror boxes with technology, namely Augmented Reality(AR) [86]. The research investigated whether their system, Augmented Mirror Box (AMB), is as effective in aiding rehabilitation and reliving phantom pain as Optical Mirror Box (OMB). The AMB, is comprised of two boxes in which the participant places their hands inside. Inside each box, there is a webcam that records what the hand is doing and displays it on a monitor located on top of the box. A therapist is able to assigns tasks and manipulate what is displayed on the monitor via their own computer. The below figure shows the webcam settings the therapist is able to manipulate.



Mirror Box, source from [86]

A study was conducted on healthy individuals to see whether the brain can be tricked in identifying manipulation of their hands. The study showed that participants were tricked 3 times more in the AMB compared to OMB. The research also included a trial on a patient suffering from Complex Regional Pain

Syndrome and reported a decrease in the patients pain when using AMB. The system did have to be modified to track the patient's feet instead of hands. This research shows the potential and advantage of AMB: has OMB characteristics, can track impaired and normal hand movements, can provide feedback, the view can be augmented, movements can be mirrored or asymmetrical. The only disadvantage is that the system is still in the prototype stage and as such can be bulky and requires an expert to operate, but future work is being carried out to improve the AMB so this shouldn't be a problem.

I am able IamAble [27] is a company who specializes in creating solutions for patient recovery after a brain injury. They currently have two systems available for patients and healthcare professionals:

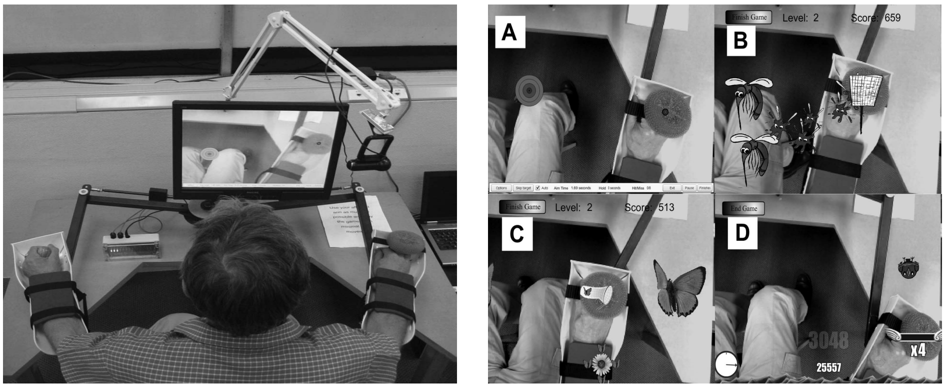
1. **Ablex -** is similar to a handlebar with a Wii remote attached. It allows the patients impaired arm to be moved around by their good arm by holding onto the controller. This is done to encourage brain plasticity.
2. **AbleM -** is a mouse like device that is strapped to the patient's impaired arm. It has a mouse button on a moveable arm which the clinician can position. This requires the patient to either move their wrist or individual fingers to touch the mouse button as directed by the clinician.

(a) Ablex (b) ableM

Figure 2.26: I am able Controllers, source from [27]

Each system has been clinically tested and comes with a series of serious games and exercise routines to help in patient recovery. The author was fortunate enough to see such systems in person and even view the prototype tradition. One interesting research studyd was on bilateral upper limb movement, which is consider the companies best prototype but currently too cumbersome to setup in patients home

[28]. The researcher involved testing their system Bilateral Upper Limb Trainer (BUiLT) with the use of VR through serious games. The results of the study were positive with motivation and engagement from participants being high with reports of enjoyment during the therapy. Further research is recommended on a larger sample size and wider range of stroke survivors to validate their initial results.



(a) BUiLT Equipment (b) BUiLT Game View

Figure 2.27: BUiLT, source from [28]

2.9. Background Summary

In this chapter the author has:

1. Explained what a stroke is and what causes it to happen.
2. Investigated traditional methods for the treatment of a stroke.
3. Explained what Virtual Reality is.
4. Investigated the use of Virtual Reality as a tool for Rehabilitation.
5. Investigated different tracking technologies.
6. Investigated different display technologies.
7. Investigated the use of Games as a tool for Rehabilitation.
8. Investigated different Interaction Constructs for aiding Rehabilitation.

The author plans to use Virtual Reality in the form of Serious Games to aid in Stroke Rehabilitation. Where possible, the author will incorporate traditional methods, such as Action Observation Treatment and Motor Imagery, to ensure the most effective application is created.

3. Design Methodology

3.1. Research Approach

The main focus of this Masters thesis is to investigate and compare different methods of tracking, display and constructs for creating a integrated technology system to assist in the rehabilitation of stroke survivors. As there are many different forms that these methods can take, it would be beneficial to focus the investigation on specific measures of goodness or performance criteria:

- **Tracking Accuracy -** Which tracking method provides the best level of accuracy and precision?
- **Tracking Limitations -** What are the limitations associated with each tracking method?
- **Sense of Presence -** Which method provides the best level of immersion?
- **Cybersickness -** What are the side effects, if any, associated with each display method?
- **Interaction Methods -** What are the best representations and interaction constructs in terms of patient adherence to therapy protocols?
- **Evaluation metrics -** What are the best methods for measuring user performance?
- **Ease of Use -** How intuitive is each of the tracking, display, and interaction methods to use (e.g. ease of use and slope of the learning curve)?
- **Level of Enjoyment -** Which methods of tracking, display, and interaction methods provided the most enjoyment?

Generally therapists require stroke patients to carry out repeated tasks or exercise on a daily basis. When carrying out these tasks or exercises, the amount of time taken is less important than the number of movements or repetitions that are performed correctly. With this in mind, the performance requirements for such a system should be focus on **“ease of use”** and **“enjoyment”** rather than performance time. The **“ease of use”** is to ensure someone with limited or restricted movement can use the system, while **“enjoyment”** reduces the undesirable effects felt by carrying out repeated-tedious-tasks.

Effective tracking design is necessary to help the user carry out the desired task without getting distracted by complicated forms of input. In essence the tracking becomes transparent to the user (i.e. doesn’t get in the way). Effective display design will enhance the user’s ability to carry out tasks. While effective interaction methods will help the user in completing those desired tasks.

While part of this investigation will look into the design architecture of the Ghost system, to be relevant, the system itself needs to be tested within a representative application that has been designed for stroke survivors. This will ensure that selection and tradeoff of technologies above are accomplished with the end goals in mind.

Research Questions
The following research questions arise from these research investigations:

1. What is the best method for patient limb tracking for stroke rehabilitation applications?
2. What is the best method of displaying spatial instructional information to the patient?
3. What are the best methods of representation and interaction for stroke rehabilitation applications?
4. What is the best method measuring patient progress in stroke rehabilitation using the Ghost system?

Prototype
In order to address the research questions above, several prototype systems were designed with different tracking and display technologies alongside different interaction methods. To make sure the prototype was designed with the user and task in mind a rigorous interaction design process was executed.

Use of Interaction Design
To design a new rehabilitation therapy system such as the Ghost we followed a “User Centered Interaction Design” approach that cycles and recycles through a series of design steps until the desired system/solution is reached. Our process involves the following steps:

- User Needs Analysis
- Designing to meet those needs
- Creating a prototype implementation
- Evaluate the prototype

The below diagram shows this process, which we describe in more detail in the rest of this chapter:

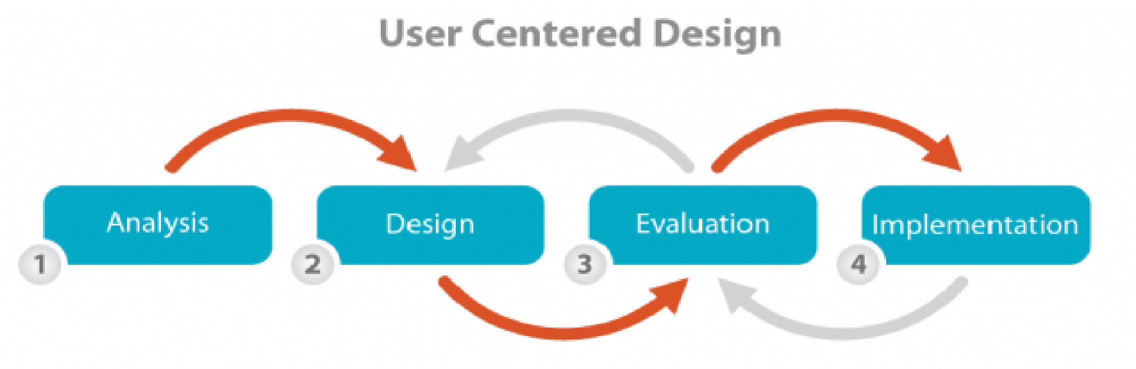


Figure 3.1: User Centered Design Approach, source from [29].

User Needs Analysis
There are many different methods that can be used for gathering user needs. The following methods were used in this research:

- **Observation -** This involves watching stroke survivors carry out daily tasks in an effort to gain new insights into rehabilitation process. Often times, users will forget to pass on key points or information on how they carry out their rehabilitation as it becomes second nature to them. This method was mainly achieved, by the author observing and analyzing a series of YouTube Videos posted by stroke survivors during home rehabilitation.
- **Identifying the user environment and tools -** This method involves gaining an understanding of what rehabilitation tools are currently being used, and where they are being used (environment). The environment will influence how the tool is used, while understanding of the tool will help to identify strengths and deficiencies that must be improved upon or eliminated. This method was mainly achieved, by the author, through reading research papers on previous work done in this area.

- **Personas -** Designing for a diverse group of users can be difficult. A persona is a fictional character that the researcher creates which embodies key characteristics of the target user group. The researcher can then focus on designing a suitable system for this one archetypical character with the knock on effect of the design being useful for the target group as a whole.
- **Interviews -** This method provides deep insight into the research problem. It involves talking to target users to discuss their rehabilitation and the problems/limitations they are currently facing with the current work methods and tools they are using.
- **Group discussions -** Facilitating a group of users in an open discussion or debate can highlight differences in opinion between what users perceive as problems with current work methods. This method was mainly achieved by the author obtaining expert group feedback on presentations about the project.
- **Users included in the design process -** This method involves users being deeply integrated within the whole design process. The approach works by having the users help design a solution that focuses on their needs; all the while they are being guided by the researcher through the correct processes involved in creating such a solution. This ensures that the best possible outcome for the Ghost system design is reached through continuous user feedback. In the case the Ghost system the users include both the patients and the therapists.

3.2. User & Task Analysis

To gain an understanding of the challenges and difficulties faced by stroke survivors, and therapists, a study of their environment, rehabilitation process, and tasks is needed. By undergoing this process, key design elements can be identified and evaluated: such as patients' ability to interact with and operate technology, or the location where Ghost will be used. This analysis and study will highlight items that need to be improved, as well as key components needed for an optimal system. During the design process, all stakeholders will engaged in order to reinforce design decisions for the prototypes.

Research Papers
Research papers were sought on the topic of stroke therapy, Virtual Reality rehabilitation, neuroscience and serious gaming. This was to identify and provide knowledge to define the foundation on which to build the research project. The key points being investigated where:

- What is a stroke.
- What causes it.
- How does it affect an individual.
- Current solutions and treatments used.
- New methods currently being investigated.

Prior research regarding these key points will serve as a corpus of prior work that will guide the development of Ghost prototypes.

Observational Study Direct observation will provide valuable insights into the user's world. We can witness the procedures patients and therapists experience on a typical day; seeing what challenges they face and how they overcome these challenges. Cross referencing observational findings with the findings from research papers will help identify key issues that need to be addressed in Ghost designs.

Expert Interviews
Five Interviews were conducted with experts on stroke therapy from different backgrounds. The interview process was mixed with both structured and open interview questions. In three of the five interviews, questions were asked to clarify aspects of stroke treatment as well as questions to gain more insight. The persona for the research project was also discussed in the interviews. After the formal interview questions were addressed, the interview entered into an open discussion where the conversation was allowed to continue into a wide range of topics around stroke treatment. For example, in one of the interviews, the main topic was on knee rehabilitation done in Poland. The treatment process was explained and how a solution was developed using technology.

Presentations
Presentations where made to several different groups. The aim of these presentations were the following:

- To make people aware of the research project.
- To seek feedback on findings.
- To seek feedback on prototypes.
- To see what users want addressed in the research project.
- To gain support and involve people in the project.

4. Prototype Development

4.1. Design Process

Interaction Design
This section will outlines the Interaction Design process to create a prototype that can be used for stroke rehabilitation. There four key functions of this prototype: 1) accurately track and provide a reliable means of patient input: 2) provide output via a display; 3) keep patients engaged; and 4) allow for collaboration during a rehabilitation exercise or task. The prototype design is organized into four functional elements:

- Tracking Device
- Display Device
- Serious Game
- Collaboration

As stated in the previous chapter, User-Centered Design approach was used for designing and evaluating the prototype, in which the users needs, wants and limitations were sought and analyzed. By reviewing the information gathered in these activities we are able to address the requirements of the users and take into account the needs of the other stakeholders. As versions of the prototype were designed and built, feedback was sought to ensure the highest quality was achieved.

Distilling the information gathered from research papers, observation studies, expert interviews, and group presentations, we conclude that a usable Ghost system design needs to fulfill the following rehabilitation issues:

1. **Reaching Tasks -** Upper body rehabilitation is generally neglected in stroke patients with lower body rehabilitation (ability to walk) deemed to be of higher importance.

2. **Time -** There is no time limit or constraint with stroke patients completing tasks such as dressing themselves. Completing the task is more important than the time it takes for completion.

3. **Engagement -** Depression and motivation are big problems among stroke patients. Increasing patient motivation and maintaining their attention in rehabilitation exercises is an essential focus.

Lesson learned from the Needs Analysis indicate that games can play an important role in rehabilitation. Games offer high levels of engagement, immediate feedback, rewards and a level of enjoyment sought by users. Our approach is to incorporate elements of rehabilitation exercises into games so as to make exercising fun as well as therapudic. The game Punching Duck [24] was highlighted as a good place to start. It provides reaching tasks in a game medium with background research conducted showing it's potential.

Weekly Presentations
Weekly presentations on project progress and findings were given to researchers from the HITLab NZ to get continued feedback on the prototype development. The benefits of these presentations were the following:

1. **Milestones -** Weekly provided milestones and deadlines

2. **Understanding -** Feedback was given on research findings and helped reinforce understanding of the research project.

3. **Weakness -** Feedback was given on research approach and highlighted any missing or weak parts of the research project.

This method of weekly presentations helped to reinforce understanding of the research problem and highlighting any weaknesses. It also ensured that the research methods being used were suitable and that the outcome of the research was to the highest standard.

Personas
Personas were created to as part of User Analysis to provide a profile of a typical user: a person who is recovering from a stroke. Three initial personas were created to this end: a single man, a young mother of 2 and an elderly couple. These personas went into a presentation which was shown to other researchers to gain feedback.

Figure 4.1: Created Personas, source from [30–32].

1. **Billy Mo -** young student who suffered a stroke from alcohol, smoking and drugs.
2. **Leona -** mother who suffered a stroke from high blood pressure.
3. **Paddy and Mary -** elderly couple who have strokes.

The feedback from the researchers indicated that while it was a good starting point, the personas needed more real world information or human elements attached to them to become true personas. It was suggested that the personas be shown to therapists so that elements gained from their patient interaction could be incorporated back into the personas. From interactions with a therapist on building a persona, information was gained about the process involved in handling stroke patients from the time they are committed to a hospital to when they are released from care. One therapist also highlighted that each patient is unique and will be affected in different ways from a stroke. Interactions with the therapist revealed that the patient's rehabilitation in the hospital is focused on walking in order for the patients rehabilitation to continue from a home environment. Home rehabilitation is the environment where patients lack the most support and where Ghost can have the most impact. In continuing this research we focused on the following patient conditions:

1. **Stroke on the left side of the brain -** This stroke location affects memory and produces attention disorders. Generally these patients will have movement problems on the right side of their body, and since a majority of people are right handed, we remove the problem associated with non-dominant side affected by strokes: generally people have a preference in limb dominance; so right handed people will always use their right hand in tasks when possible - even climb stairs , people will lead with their right leg if right handed. If a stroke affects someones dominant side, it is easier for rehabilitation as they have a tendency to naturally use that side. But if a

stroke affects the non-dominant side, then the patient must constantly remind themselves to use the stroke affected non-dominant side, even in simple tasks such as opening doors or climbing stairs.

2. **6 months post stroke -** Recovery speeds slow down after 6 months and this is where patient motivation needs to be maintained to regain their pre-stroke perceptual and motor abilities.

3. **Patient movement -** The patient has the capacity to perform antigravity movement against gravity.

    a) The range of movement was below 50% normal elbow extension.

    b) Minimum of 30 degrees shoulder flexion with elbow extension of 20 degrees.

4. **Independence -** The patient has some level of independence.

    a) The patients are living at home without the need of carer support.

5. **Upper body -** The patient recovery is focused on upper arm extensions.

6. **Dominant hand -** The patients dominant side is right side - right handed.

4.2. Clinicians

The involvement of clinicians during the development of the prototypes helped to ensure the best possible outcome was achieved. These forms of interaction helped create the final prototype used in experiments.

The initial concept was to use serious games to help with rehabilitation. It was suggested by one researcher that we investigate Punching Duck [24] due to the positive findings from the research . The Punching Duck game was then presented and discussed in interviews and presentations to experts. The experts gave positive feedback, with one group highlighting how it could help patients with visual neglect if it involved looking around on a display screen.

An initial prototype was then created based on the findings in Punching Duck. This prototype involved the creation of a 3D model (Stroke Template) to form the framework for creating an appropriate serious game. The template showed the reach locations required for patients based on the therapists requirements as outlined in Punching Duck. The core representation and interaction constructs of the prototype was a red cube appearing at one of the reach locations that the user would turn green by touching it with a 3D arm they controlled via the Kinect V1. This prototype was shown in subsequent presentations and interviews by the author to elicit feedback on the template and direction of research.

The prototype design then evolved to include artwork and game elements such as positive feedback to patients based on their performance. The artwork and game elements were derived from lessons learned by the author from clinicians and patients on a similar research project associated with Parkinson's disease rehabilitation [87].

4.3. Stroke Rehabilitation Exercise

Stroke Template
A stroke template is a 3D model that shows the reach locations used by therapists as part of a rehabilitation exercise. Reaching tasks or exercises help in improving mobility in the impaired limbs of stroke patients. The stroke template is based on the research conducted with Punching Duck [**?**]. The 3D model consists of a number of 3D cubes placed at different locations that the user is required to reach out and touch during the game:

Punching Duck provided the following diagrams in their research papers:

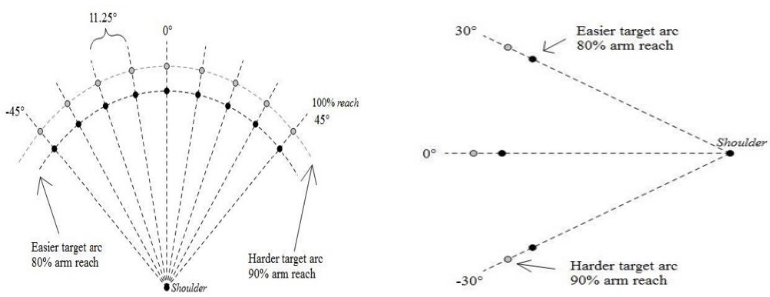


Figure 4.2: Reach locations in Punch Punch Duck, source from [24].

From the above diagrams a 3D template for reach locations was created in Blender 3D modelling program [88]. The followimg figure shows the template being used in Unity3d [89] with a 3D arm model:

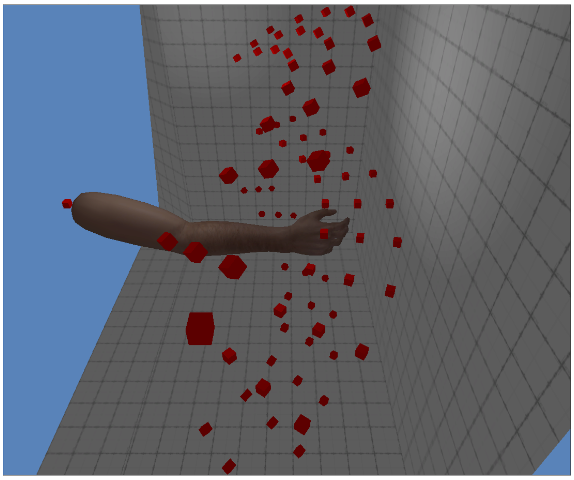


Figure 4.3: 3D Reach Location Template for Unity3d complete with 3D arm model (Stroke Template)

The 3D template in Figure 4.3 was then brought into a Unity3D project where a Unity3D package was created for future game development using the reaching task (for the researchers or other individuals). The package provides the 3D position of each reach target as well as a unique name that represents its row, reach range and orientation. The Unity3D package and project setup were verified by a rehabilitation expert to ensure that the 3D template was correct.

The advantage of creating a 3D template is that it can be passed onto game developers to create serious games for reaching tasks. The developers can then create gameplay based around the reach points. This will help reinforce the requirements set by therapists for the serious games.

Based on the 3D template, a simple game was created. As shown in Figure 9.1, The gameplay involves causing a red box to appear at a reach target location; the user touches the red box with a 3D arm controlled via the Kinect V1; the red box turns green for a second; a new red box appears in a different location and the process repeats.

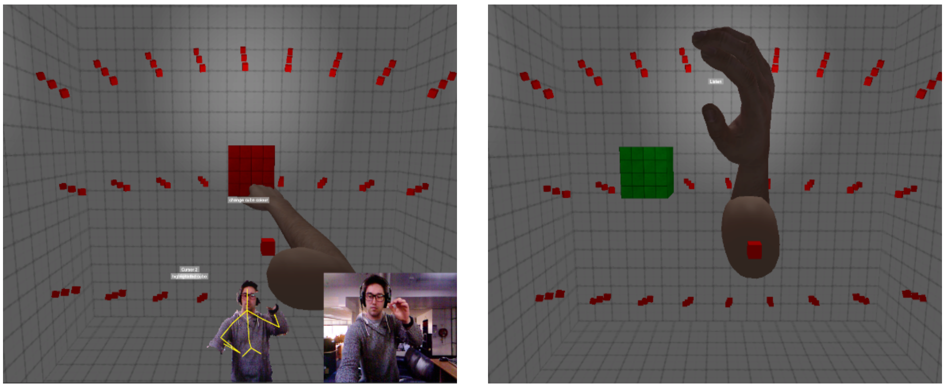


Figure 4.4: Stroke Template Demo showing reach locations and ability of 3D arm to collect or touch them.

Inverse Kinematics

The Mouse, Myo, Flock and DTrack were selected to obtain tracking information from patients. In order to control the 3D virtual arm with the tracking data inverse kinematics is needed. Inverse kinematics is the opposite of forward kinematics. Forward kinematics is how humans move their limbs: each joint position defines the next joint position for the end state of a limb position in 3D space. Inverse kinematics is commonly used in robotics as the end state defines the positions of the joints of the robotic limb. For example, forward kinematics can be experienced by moving your upper arm around. You will notice that the lower arm and wrist positions change as you move your upper arm around. Inverse kinematics would be the opposite to this. So by moving your wrist, you would be defining the positions of your lower and upper arm. See Figure 4.5 for a screenshot of Inverse Kinematics being used by a computer mouse to control a 3D arm model.

In the case of our candidate tracking devices, we have one input via a device (Mouse. Myo, Flock or DTrack) that we use to define the wrist position of the 3D arm. Using inverse kinematics, we then calculate the positions of the elbow and shoulder joints to determine the end state of the 3D arm.

Each of the input devices either takes control of the game cursor or the 3D game object of the wrist of the 3D arm. Inverse kinematics allows the rest of the arm to follow the wrist in a natural movement pattern. In the case of the authors experiments, several prototypes were created: one for each of the input devices.

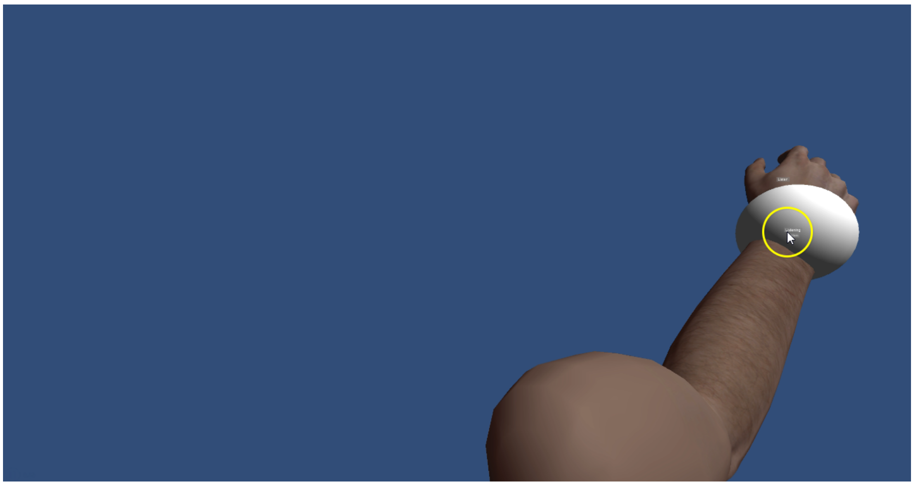


Figure 4.5: Inverse Kinematics being used by a computer mouse to control a 3D arm model in Unity3d.

In the case of Flock and DTrack, depth or z-axis information was provided. However, for the mouse and Myo a different approach was needed to supply the z-axis. The mouse used a mouse button down approach to increase the z-axis and then by releasing the mouse button, to lower the z-axis to a minimum value. The Myo used a combination of two gestures: wave in and wave out(standard gestures supplied by the Myo sdk/console), to control the z-axis value by lowering or increasing the amount.

Butterfly Mini Game

Based on the stroke template prototype, the author created a serious game for use in evaluating prototype configurations. The gameplay involved 3D butterflies appearing one by one which the user caught using the hand of the 3D arm. The 3D arm had a Ghost Occlusion effect (shader) applied to it that the user controlled via a Kinect V1. The goal of the game was to catch 10 butterflies with feedback on game length and performance provided during the game with an overall performance summary supplied upon completing the game. The following figure is a screenshot of the Butterfly game based on the Unity3d Stroke template described earlier. It uses the Kinect V1 as an input device and provides feedback to the user on the Kinect V1 tracking.

Figure 4.6: Prototype of the Butterfly Game working with Kinect V1 as input device.

4.4. Ghost Flow Chart

The Ghost concept for stroke rehabilitation requires a number of interacting subsystems or elements. This complexity is exacerbated since there are really two users, the patient and the therapist. Shown in Figure 4.7 is a system block diagram showing the hardware and software components that must be integrated to create a viable Ghost system.

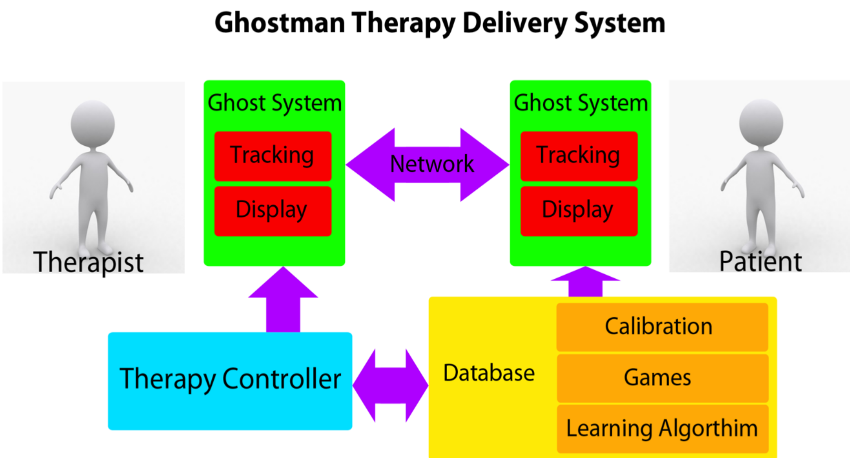


Figure 4.7: A chart showing an overview of the Ghost System.

Key elements of the Ghost system are described below:

1. **Ghost System -** The Ghost system is operated both by the therapist and patient. The system involves a form of tracking and display as a means of

input and output for interaction by both users. The therapist generates the exercise task while the user performs the task.

2. **Network -** The two systems allow for communication between the two users via the internet/network.
3. **Database -** The patient has access to serious games for rehabilitation. There is a calibration component to make sure the tracking is optimal as well as a learning algorithm that adjusts game difficulty based upon patients condition/performance. The database stores all of the patients performance and scores during their rehabilitation program.
4. **Therapy Controller -** The therapist has access to the database and can view the patients performance and adjust the games the patients can play, create a rehabilitation program for the patient to follow, and override or adjust the learning algorithm based on their professional opinion.

4.5. Prototype Components - Interaction Constructs

Four candidate prototypes were created to explore different interaction methods and interface representations. These categories are outlined below and discussed more in the following subsections:

1. **Special Effects -** How to promote effective communication between the two users by providing feedback mechanisms and visual effects.
2. **Patient -** The best approach and special effects to use from the patients perspective.
3. **Therapist -** The best approach and special effects to use from the therapist's perspective.
4. **Collaboration -** A prototype to allow two users to communicate and work together in real time from two separate locations.

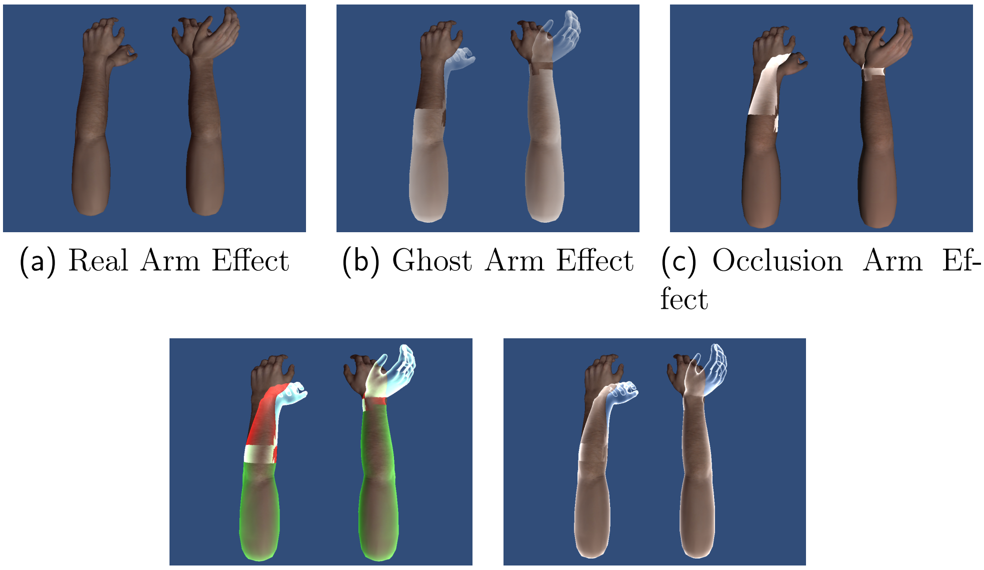
Special Effects
Ghost prototypes generate a virtual arm representing the remote therapist that is overlaid on the local users virtual arm. So one of the key challenges is how to directly overlay the two user's virtual arms on top of each other. This highlights the need for additional feedback mechanisms or effects. To address this issue, a

number of different effects were created with the use of shaders on 3D arm models in Unity3D. These shaders ranged in a wide variety of colours and effects. Figure 4.8 shows some of effects created. The effects in the figure range from different imaging and computer game techniques as well as a variety of colours to provide feedback to the user on what is happening on the screen.

Figure 4.8: Some of the Special Effects created during the development of Ghost.

To test each of the shaders, prototypes were made with two sets of left and right arms in a fixed position. One set of arms acted as the patient and the other the therapist. The left hand of the therapist was raised above the left patient hand while the right hand of the therapist was lowered below the patient right hand. This fixed position allowed the researcher to see the effects the shaders were having on the 3D arms. The layout of the 3D arms also simulated a collaboration between therapist and patient and allowed for the strength and weakness of each shader(special effect) to be seen.

Five special effects were chosen for the Interaction experiment. The same effects were used in both patient and therapist conditions:



(a) Real Arm Effect (b) Ghost Arm Effect (c) Occlusion Arm Effect

(d) Colour Arm Effect (e) Ghost Occlusion Arm Effect

Figure 4.9: Selected Special Effects chosen for the Ghost System.

The special effects were incorporated into a special build of the butterfly game. The number of butterflies to complete the game was changed from 10 to 15. This was to allow the special effect to cycle through the different arm representations at every 3rd butterfly caught.

- **Butterfly 1-3** was Real Arm
- **Butterfly 4-6** was Ghost Arm
- **Butterfly 7-9** was Occlusion Arm
- **Butterfly 10-12** was Colour Arm
- **Butterfly 13-15** was Ghost Occlusion Arm

Patient
To test local interaction constructs, a special build of the butterfly game was created to simulate a patient(controlled by the user) following a therapist. This build involved creating a second 3D arm controlled by Artificial Intelligence(AI). The AI moves with the use of inverse kinematics. The game works by the AI hand position moving to a reach location outlined in the stroke template. Once the hand stops moving, a butterfly appears for the user to catch. Once the patient catches

the butterfly, the therapist(AI) arm would move to a new position and another butterfly would spawn. The catching of the butterflies ensured the patients arm would align to the therapist arm for the special effects to be seen. **Note:** That both patient and therapist conditions build on top of the special effects build, so every 3rd butterfly changes to a different special effect.

Therapist
A similar method for the patient was used for the therapist interaction construct. The therapist arm is now controlled by the user who guides the patient arm (controlled by AI) through a series of exercises. The patient arm moves with the help of inverse kinematics. To help guide the user (therapist) in guiding the patient, a butterfly would spawn at a reach location. The user then catches the butterfly for the patient arm to move. Once the patients hand reaches the reach location, a new butterfly will spawn allowing the therapist to continue the rehabilitation exercise.

Collaboration
For collaboration, a networking solution was created which allowed full body tracking of two Kinect avatars and users. The first solution was created using a free service called photon cloud [90] with Unity3D. However, there was a latency effect due to the server being hosted in Asia. The advantages of the approach are that there is no server needing to be setup for the collaboration to take place, but due to the nature of medical data on top of the latency, another approach was implemented.

The second approach involved the use of a plugin called Bolt [91] networking which was still in development at the time. This plugin allowed for a secure server to be setup with administrator access and control. The therapist and patient are then able to connect from each of their systems into a virtual room where they can then conduct their rehabilitation exercises.

One other approach was investigated by the researcher: the use of one user hosting the session. The problem associated with this approach is that the host system may crash or a network problem occurs from their side. This would result in the session being canceled for every user involved in the virtual room unless a protocol is put into place to allow for the hosting to move to another user. Another disadvantage of this approach is latency. The hosting user will experience little to no latency while the other user may experience varying degrees of latency depending on a number of networking factors. The following figure is a screenshot of the networking code of bolt working with a client connecting to the Ghost server.

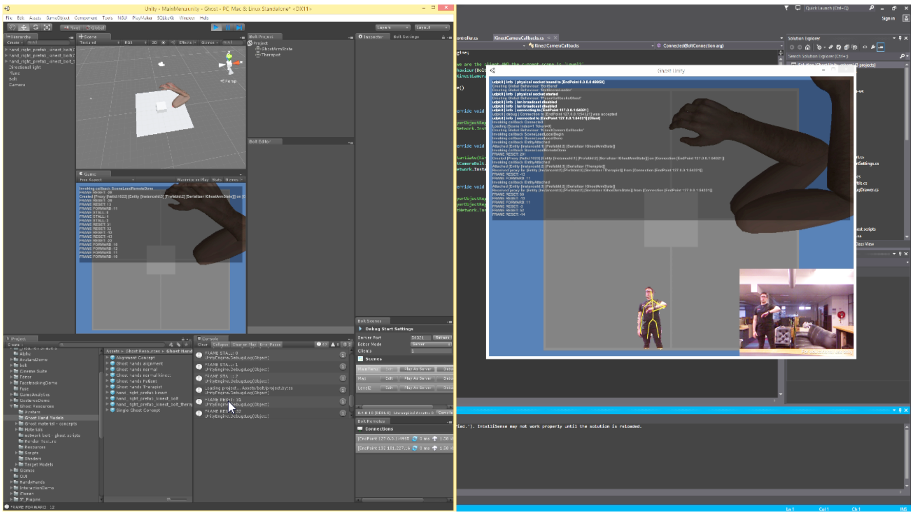


Figure 4.10: Collaboration Demo showing the client and server application working together.

4.6. Final Design

Finished Butterfly Game

The final version of the Butterfly game (Figure 4.11) was used as the foundation for all experiments, with various conditions implemented into the system as needed. This is described in detail in Chapter 5.

Figure 4.11: Final Version of the Butterfly Game that will be used as the base of all experiments as part of the research project.

Summary
Due to the number of prototypes created, separate experiments were run to test different categories of conditions: Tracking, Display, Adherence, Serious Game, and Online Collaboration(see Chapter 6). Prototypes were placed into a category depending on their purpose.

In this chapter we have outlined and discussed the following:

1. **Interaction Design -** The process in designing prototypes for the Ghost system.
2. **Feedback from Clinicians -** The information gained from interactions with clinicians on the research project throughout various stages.
3. **Stroke Rehabilitation Exercise -** The creation of a serious game for stroke rehabilitation as well as a tool to help create future serious games.
4. **Ghost Flowchart -** A high level overview of the Ghost framework.
5. **Prototype components -** Various components of the Ghost system that need to be addressed.
6. **Serious game tasking -** The development of a serious game that can be used to test the viability of the Ghost component configurations for stroke rehabilitation.

5. Butterfly Stroke Game

In this chapter, the researcher presents the serious game that was used for Ghost. The focus of the game was reaching tasks as outlined in Chapter 4.3. The game also forms the basis for all experiments conducted as part of this research project.

Based on lessons learned from user needs analysis, it was determined that a serious game focusing on reaching tasks would satisfy the requirements for a stroke rehabilitation exercise. Therapist see the advantage of combining repetitive movements associated with rehabilitation exercises with games for motivation and retention, as long as the correct movements were performed by the patients throughout the game. Therapists have commented on Nintendo Wii fit games initially as being highly favoured, until the patient determines that they do not need to perform the movements correctly to complete the game and they could get higher scores through the use of incorrect movements; for example, waving Wii remote frantically while close to the display.

5.1. Game Design

The gameplay of the Butterfly game involves the user controlling a virtual 3D arm that they use to catch a certain number of butterflies as fast as they can. The butterfly location, and underlying game mechanics are based on reaching tasks for a stroke rehabilitation exercise. Figure **??** is a screenshot of the stroke template taken from front view. It shows the reach target locations that was used to build the Butterfly Game. The stroke template is outlined in Chapter 4.3.

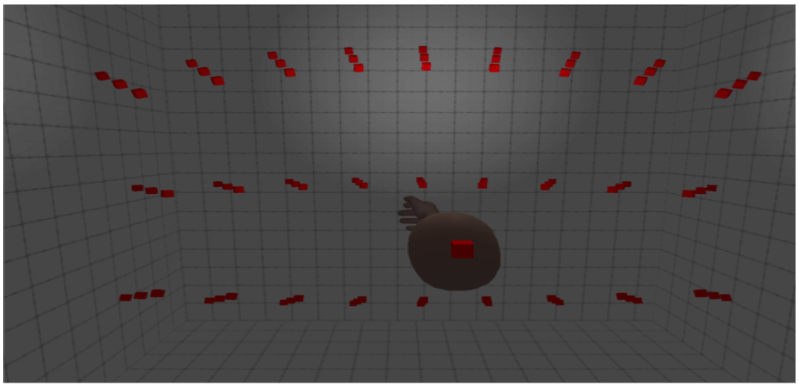


Figure 5.1: Stroke Template Front View

The template allows for the implementation of reaching tasks as part of a rehabilitation exercise. The author's method of reaching tasks is an adaption of the tasks originally designed and tested by [24]. In their experiment, six stroke patients were recruited for the reaching tasks in the game to be tested. The equipment used was a Kinect V1 and a large screen TV. Their participants were chosen based on the type of stroke they had experienced and the limitations imposed in their current health state. They had to: (1) have experienced unilateral hemispheric ischemic stroke in the last 3 months - 7 years; (2) be a minimum of 18 years old; and (3) suffering impairment with a minimum of 30 degree voluntary shoulder flexion with 20 degree elbow extension. Their game design involved reach locations that had different amounts of points associated with them. More challenging reach locations had higher points while easier targets had less. The user gained points by punching each target with the 3D arm they controlled in the game. Figure 5.2 shows the game view of Punch Punch Duck. You can see the 3D arm which is controlled by the user. They use this 3D arm to knock down the targets which have point values overlaid on top of them. There is also a score board located in the top left had corner to give feedback to the users on their performance.

Figure 5.2: Punch Punch Duck Game, source from [24]

In the author's Butterfly game, the user's task is to move the virtual hand of the 3D arm they control to the location of a 3D butterfly (reach target location). Touching the butterfly with the 3D hand signals that the butterfly has been caught and a new butterfly will appear at a different reach location. The user keeps catching the butterflies until there are none left to catch. There is no time limitation placed on the game, but user time is recorded as a performance indicator. This strategy was used since time is not deemed to be important for stroke people when undertaking therapy tasks such as this.

The number of butterflies to catch is currently set to 10 but can be adjusted based on the number of reaches required by the therapist for that patient. The types of butterflies displayed are selected randomly from amongst a set of pre-made models. The locations and orientations of the butterflies is determined by the stroke template outlined in Chapter 4.3. From the template, 10 reach locations were selected by the author. The chosen reach locations were placed into an array and randomly shuffled by an algorithm at the start of every game. This helped to ensure the order in which the users collect the butterflies is different every time. The butterflies flap their wings but do not move from the reach location as the feature of moving targets can be implemented in future work as a more challenging setting for patients, once they become proficient at the game. Figure 5.3 shows the reach locations selected to be used for the Butterfly Game and the Ghost experiments.

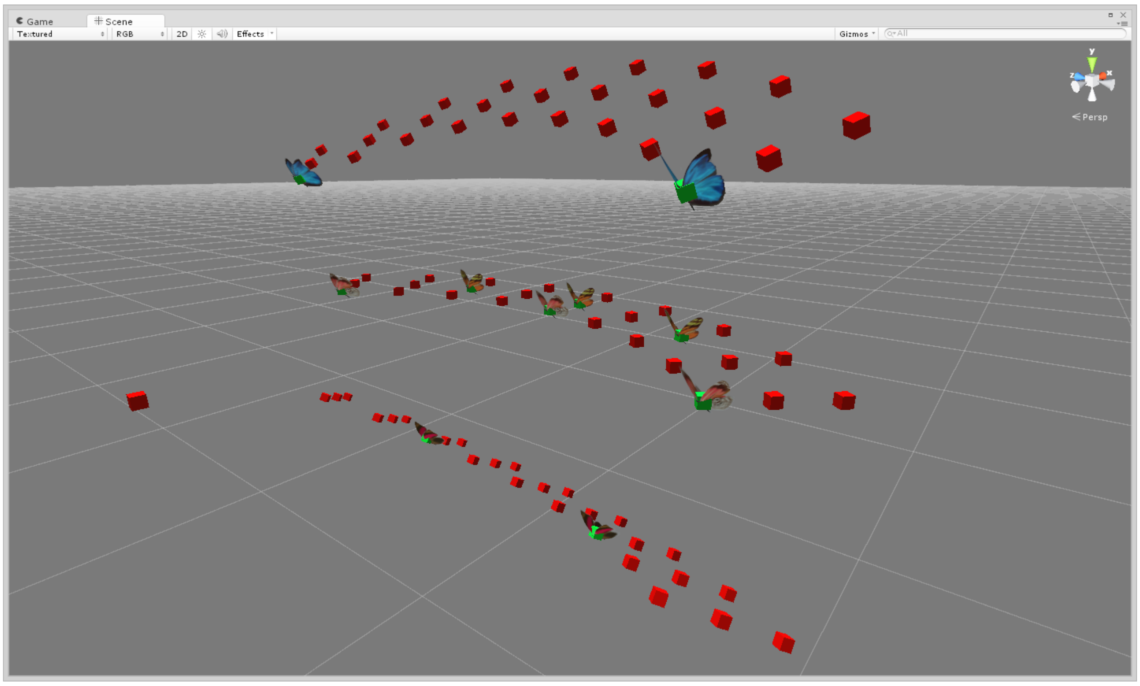


Figure 5.3: This figure shows the 10 Reach Locations used in the Butterfly Game

Note: Each butterfly can only be caught with the virtual hand of the 3D arm and not any other part of the model. This is due to physics and collision detection only being implemented on the hand part of the model. This was configured to ensure that the user moves the hand to the required reach target location and not accidentally catch butterflies with other parts of the 3D arm by mistake.

Gameplay Summary

Figure **??** shows the final design of the Butterfly Game. It includes the particles for Butterfly spawning, which represents reach locations, to the cursors on the ground and HUD to allow the user to navigate the 3D within the 3D world.

Figure 5.4: Final Version of Butterfly Game

5.2. Game Implementation

Software Used
The following software was used to create the Butterfly game:

1. **Unity3d -** A game engine used as the main tool in creating the Butterfly game.
2. **Photoshop -** Was used for any textures or images required in making the Butterfly game.
3. **Blender -** Used to create any 3D models that were needed.
4. **VRPN -** A custom built version of VRPN was made to work with the Raspberry Pi to connect the Flock of Birds tracker to Unity3d.
5. **UIVA -** A custom built version of UIVA was built to communicate with VRPN to Unity3d.
6. **Source Tree -** Used for version control.
7. **Bitbucket -** Used to store the Butterfly game and its version online
8. **Trello -** Used to create jobs/tasks and breakdown the components necessary in making the Butterfly game.
9. **Google Drive -** Was used for any documentation.

Software Modules
The following SDK's were used:

1. **Kinect 1.8 SDK for Kinect V1 -** This allowed the Kinect V1 to be used for input [92].
2. **Kinect 2.0 SDK for Kinect V2 -** This allowed the Kinect V2 to be used for input [93].
3. **Myo SDK -** This allowed the Myo to be used as an input device [94].
4. **Oculus SDK -** This allowed the Oculus to be used as an output device [95].

The following plugins were used in Unity3d to build the Butterfly game:

1. **Playmaker -** A visual coding environment for Unity3d. The author used this as the main tool in Unity3d and created additional actions/scripts as needed.
2. **Playmaker Array -** Used to define and keep track of reach target locations for butterfly spawning.
3. **Playmaker NGUI -** This was used to control the interaction on the Butterfly GUI.
4. **Final IK -** Used to allow inverse kinematics on the user controlled 3D arm model.
5. **FPS Handy Hands -** The 3D arm models used to represent the users arms.
6. **Kinect v2 with MS-SDK -** This allowed communication between Kinect V1 and V2 to the Butterfly game.
7. **Oculus -** For communication between the Oculus Rift and the Butterfly game.
8. **NGUI: Next-Gen UI -** The main tool used in creating the GUI for the Butterfly game.
9. **NGUI: HUD Text -** This allowed popup words on the screen to provide feedback and encouragement to the users.
10. **Mobile Cartoon GUI -** This was the artwork that was used for the Butterfly GUI.
11. **Ghost and X-ray incl Shader Combine Tool -** This was used to create shaders for the special effects on the 3D arm models.

12. **Heathen's Occluded Render Essentials -** The main shader plugin which was used for special effects on the 3D arms.
13. **Easy Save 2 -** This was used to create text files to store game data from users.
14. **ADL SCORM -** This is needed to allow Unity3d webplayer apps to work inside the Moodle framework.
15. **iTween -** This is used to create advanced transform and orientation movements.
16. **Waypointer -** This is used to create the shadows or guides on the ground for the butterflies and 3D arm model.
17. **Toon Level Kit -** This was the main artwork used to create the game.
18. **Advanced PlayerPrefs Window -** This was used to expose local user settings.
19. **Animal Friends -** This was used to add animal character to the Butterfly game.
20. **Cartoon FX Pack 2 -** This was used to create particles and special effects for the spawning and catching of butterflies.
21. **SQLiteKit -** This was used to store data on the game in a local SQL database.

The following plugins were also included in the Unity3d project in the creation of other prototypes alongside the Butterfly Game:

1. **Bolt Networking -** To provide network communication for collaboration.
2. **Game Analytics -** To collect and analysis user data online.
3. **Universal Sound FX -** This is used to provide greater control over sound.
4. **SoundManagerPro: Next-Gen Audio and Sound Toolkit -** Alternative plugin for sound control.
5. **Raw Mocap Data -** This is used to record a user's movement to create animation with the use of the Kinect V1.
6. **LeanTween -** This is a lightweight framework for advanced transform and orientation movement.

7. **Graph Maker -** Used to create graphical charts as feedback to the user on their performance.
8. **Good Old Sockets -** This is used to get around the limitations placed on the free version of Unity3d.
9. **Cartoon 65 Seamless Textures -** This provides colourful textures that work with the designed theme for Ghost games.
10. **Dark Stone GUI -** This was an alternative GUI artwork.
11. **SECT Complete -** This provides performance benefits from occlusion methods.
12. **Kinect with MS-SDK -** This provides access to a framework to use Kinect V1
13. **KinectExtras with MS-SDK -** This includes additional features for Kinect V1, such as speech and facial recognition.
14. **Kinect and KinectExtras with MS-SDK Playmaker Actions -** This was written by the author to provide access to Kinect and KinectExtras with MS-SDK within playmaker coding environment.
15. **Maximo Fuse -** This is a software tool and plugin to create 3D avatars. It comes with default models that were used in Ghost prototyping for collaboration.

On top of the above SDK's and plugins used, the author created a number of scripts/code and plugins in creation of the Butterfly Game and prototypes.

1. **Playmaker ADL Scorm -** This allowed the Scorm plugin to be used within the playmaker coding environment.
2. **Playmaker NGUI: HUD Text -** This allowed control of the NGUI popup words with the playmaker coding environment.
3. **Playmaker GUI -** This allowed control over the native Unity3d GUI system within the playmaker coding environment.
4. **Playmaker Custom Actions -** Other actions and scripts were written for playmaker. Including functions for: Drawline, Follow Mouse, Application Data Path.

Obstacles
There were several challenges that had to be overcome during the making of the Butterfly Game. These ranged from special effects and artwork to device implementation, and included:

1. **Shaders and 3D arms -** To allow collaboration to effectively take place between the therapist and patient, the issue around collaborate occlusion had to be addressed: this is a term that connotes the situation when the local person's view is blocked by their collaborator's body when trying to perform a task. The solution to this problem was to create different shaders and materials to apply to 3D arm models within Unity3d. The different arms are outlined in Chapter 4.3.

2. **Conflict between Kinect V1 and V2 -** There was an issue with getting Kinect V1 and V2 to work together. This was due to a conflict in naming conventions from the two plugins. This was fixed with Kinect V1 being supported within the plugin used for Kinect V2. There was also a previous solution which involved the author renaming and restructuring both plugins to work together. Consultation with the creator of the plugins was also extremely helpful in offering support to achieve this modification.

3. **Ascension Flock of Birds and Unity3d -** The Flock of Birds is an old tracking mechanism. There was an issue with getting the tracking data output from the device and into Unity3d. This was achieved with the use of a Raspberry Pi, custom version VRPN, and custom version of UIVA. Further details of this fix is outlined in Chapter 5.5.

4. **Myo and Playmaker -** The Myo required Myo driver software to be installed on the computer and an SDK to have it work inside Unity3d. Further work was carried out with the creation of custom built playmaker actions for the Myo. This allowed the Myo to fit within the Butterfly framework with easily adjustable settings.

5. **UIVA and Playmaker -** To get the tracking data from VRPN, UIVA was used. Further work turned created scripts into custom built playmaker actions. This allowed the Myo to fit within the Butterfly framework with easily adjustable settings.

6. **Moodle with Scorm and Unity3d with Playmaker -** Multiple steps were needed to have Unity3d applications work within the Moodle learning environment. The Unity3d application had to be built as a webplayer application with the use of ADL SCORM. Scorm allows the webplayer to be used within the Moodle environment. Further work was carried out with the creation of custom built playmaker actions for Scorm. This allowed data to be exchanged between Unity3d and Moodle on users performance.

7. **Inverse Kinematics -** Inverse kinematics had to be investigated to allow control of the 3D arm by some input devices,. This involved research by the author with a final solution being implemented with the aid of plugin on the Unity3d asset store. Further work configured the inverse kinematics to with the rest of the Butterfly framework within the playmaker environment. Inverse Kinematics is also outlined in Chapter 4.3.

8. **Stroke game -** Initially Butterfly concept had to be designed. This involved deciding on the type of rehabilitation exercise to prototype.. The decision to use reaching tasks was done based suggestions from experts and experience from the author's previous research on Parkinson's disease. To further aid in the development of creating the Butterfly game, and further games, the stroke template was created as described in Chapter 4.3.

5.3. Game Components

The user interface for the game had a number of key components shown in the table below. These were designed to provide help with depth perception, performance feedback, and game mechanics.

Game Components			
Depth Perception	**Reach Gauge**	**Minimap**	**Line Render**
			
	About	**About**	**About**
	Feedback showing how straight the users arm is from the elbow.	Feedback shows location of butterflies and arm from top down view.	Feedback shows the path from hand to butterfly.
	3D Arm Shadow Cursor	**Collected Butterfly Particles**	
			
	About	**About**	
	Feedback shows z-axis location of hand on the ground.	Feedback shows when you have reached the correct depth location (reach target location).	

Table 5.1: Depth Perception Game Components

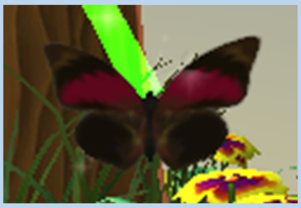
Game Mechanics	Butterfly Model	Arm Model	Butterfly Shadow Cursor
			
	About	**About**	**About**
	Reach target location.	Representing users arm: How they collect butterflies.	Butterflies location.
	Spawn Particles	**Score Particles**	**Spawn Message**
			
	About	**About**	**About**
	Highlight where butterflies is on the screen.	Show when you have collected a butterfly (reach target location).	Feedback message for spawning of butterfly.

Table 5.2: Game Mechanic Game Components Part 2

Game Mechanics	**Collected Message**	**Sound Effects**	**Turtle Feedback**
			
	About	**About**	**About**
	Feedback message for collection of butterfly.	Sounds played when butterfly collected.	Feedback when you collect a butterfly and finish the game.

Table 5.3: Performance Feedback Game Components

Performance Feedback	**Reach Target Number**	**Clock**	**Results Table**
			
	About	**About**	**About**
	Number of butterflies collected and number left to collect.	On time spent in the game.	Showing how well user has done in score and time.

Table 5.4: Game Mechanic Game Components Part 1

5.4. Variations of the Butterfly Game

All experiments use the Butterfly game as the base or core of the experiment design. However for some experiments adaptations were made in the following forms:

- **Devices -** The Tracking and Display experiments use a variety of devices as a means of input and output from the game.
- **Special Effects -** The Interaction Construct experiment used a range of different special effects on the 3D arm in the butterfly game.
- **Scorm -** The online experiment uses Scorm to allow the game to be played in Moodle via a web browser.

All experiments, except the exception of the online experiment, used the computing equipment outlined in Chapter 5.8 along with additional input and display equipment as needed.

5.5. Tracking/Input Devices

A key requirement for the game is being able to track the user's arm motions and capture user input. It this section we describe the variety of tracking and input devices that were investigated.

Mouse
A prototype was created to test mouse input. This involved attaching a gameobject to the mouse cursor and having it follow the mouse. The mouse buttons were tested by clicking on 3D cubes to change their colour.

Figure 5.5: Mouse, source from [33]

Kinect V1

The Kinect V1 hardware was used to capture user arm movement and to act as a controller or means of input. The SDK v1.8 was installed and a plugin from the Unity3D asset store(Kinect V2 with MS-SDK) was used for the Kinect V1. The first Kinect V1 prototype involved mapping of the users right arm to a 3D arm within Unity3D. The second Kinect V1 prototype involved mapping the user's full body movements to the body of a 3D avatar within Unity3D.

Figure 5.6: Kinect Version 1, source from [34]

Kinect V2

The Kinect V2 SDK 2.0 was installed and two prototypes created with the use of a plugin from the Unity3D asset store for Kinect V2. The first Kinect V2 prototype involved mapping of the users right arm to a 3D arm within Unity3D. The second Kinect V2 prototype involved mapping the user's full body movements to the body of a 3D avatar within Unity3D.

Figure 5.7: Kinect Version 2, source from [34]

Flock of Birds

There was some work necessary to get the Ascension Flock of Birds(Flock) working as an input device. The first prototype needed a Raspberry Pi(Pi) connected to the Flock via an ethernet cable. This was necessary due to the connections available on the device. The Pi was then connected to a switch that was in turn connected to a local PC. This created a chain of two local networks that allowed communication from the modern PC to the flock via the Pi.

To get the necessary tracking data from the Flock, a custom made VRPN solution was installed on the Pi that used TCIP to communicate to the flock. VRPN was then used on the modern PC to get the tracking data the Pi was receiving from the flock.

The second Flock prototype created was to get the tracking data into Unity3D. UIVA [96] was used as middleware from VRPN to Unity3D. The prototype used the Flock to control the movements and orientations of a virtual cube on the screen.

The third Flock prototype for Flock involved removing the switch and connecting the Pi to a network port to use the university network system and grant internet access to the Pi. This allowed any modern PC to communicate with the Pi directly without the need for a switch to be setup.

Figure 5.8: Ascension Flock of Birds, source from [15]

DTrack

Similar to the methods employed by the flock, the DTrack involved the use of VRPN to record the tracking data from the DTrack system. UIVA was then used to bring in the tracking information from VRPN into Unity3D. The second DTrack prototype involved controlling a cube's position and orientation with the information from a tracking marker held by the user.

The DTrack system was implemented but stopped functioning during pilot testing of the Tracking experiment outlined in Chapter 6. Among all the tracking devices during the pilot study this was the second most preferred method next to the Kinect. The author's observation for this level of performance was due to its responsiveness, and natural and intuitive ease of use. The virtual arm on the screen acted in the expected manner. This could be due to how the input device was held by the user as compared to other methods: the user would hold the tracking marker over their closed fist; This approach made the tracker an extension or part of the users arm and therefore allowed the collection of butterflies in a natural way.

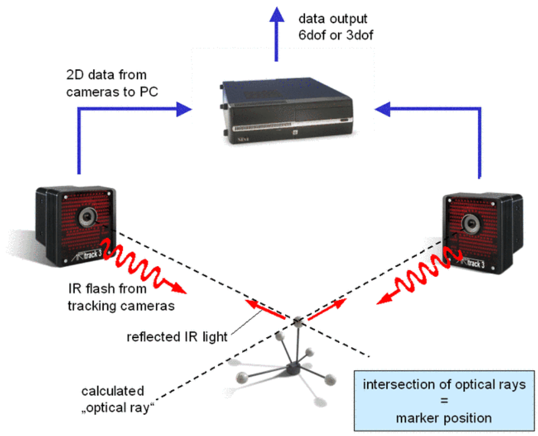


Figure 5.9: DTrack, source from [8]

Myo Armband

Several steps were required to set up the Myo Armband (Myo). The Myo console software was installed that allowed the Myo tracking data to override the input controls from a mouse in applications. For example, swipe left gestures can override or simulate the page up or mouse in Powerpoint application. The other component was the SDK for Unity3D, that allowed the creation of Myo specific applications. The first Myo prototype involved the use of gesture controls. Fingers wide and a closed grip were used to change the colour of a cube. The second version involved mapping the Myo movements to control the mouse cursor on the screen.

For the Myo prototype, different gestures had to be tried. It was found that some gestures work better for different users. In some cases the gestures would not work at all. In the end, wave in and wave out gestures were chosen based on pilot testing results. Further evidence and hypotheses are provided in the results section for the Myo.

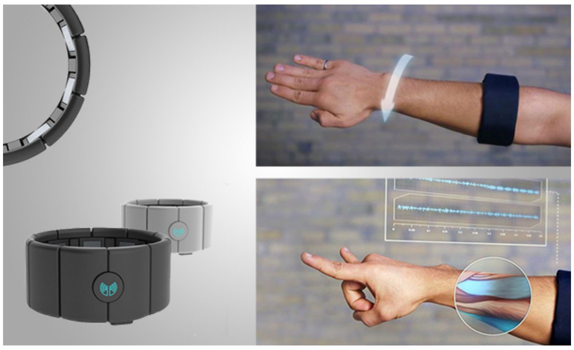


Figure 5.10: Myo Armband, source from [35]

5.6. Display Devices

Large Display
A prototype was created whereby a PC was connected to the top middle projector of the Vision Space Theatre.

Figure 5.11: This figure shows the Large Display used for the experiments

VisionSpace 2D
The VisionSpace Theatre (VS) has 3 large screens and 6 rear projectors in two rows of 3 projectors; a top and bottom row. (Note that there are two projectors assigned to each screen to create a binocular view via image polarization.) To test the 2D capabilities of the Vision Space, a prototype was created wherein the bottom row of projectors was turned on (while keeping the top row from projecting onto the screen) and a special build of the Butterfly mini game was used. The adaption of the game involved 2 additional virtual cameras that matched the layout of the 3 screens (angles to one another) to provide peripheral vision.

Figure 5.12: This figure shows the setup of the Vision Space in 2D Mode

VisionSpace 3D

To test the 3D capabilities of the VS, a special build of the Butterfly mini game was used with all 6 projectors turned on. The build included the addition of 5 virtual cameras. The layout of the cameras was in 2 rows of 3 that matched the layout of the 3 physical screens in the VS. Code was then written to offset the projection of each virtual camera: one row of cameras was for the right eye while the other for the left eye. When the application was ran it was put into window mode and stretched to cover 6000 by 768 pixel resolution. This method allowed for the necessary overlap and eye separation for the 3D effect to take place: providing 3D polarization glasses were worn to separate the left and right eye views from each of the dual projectors for each screen.

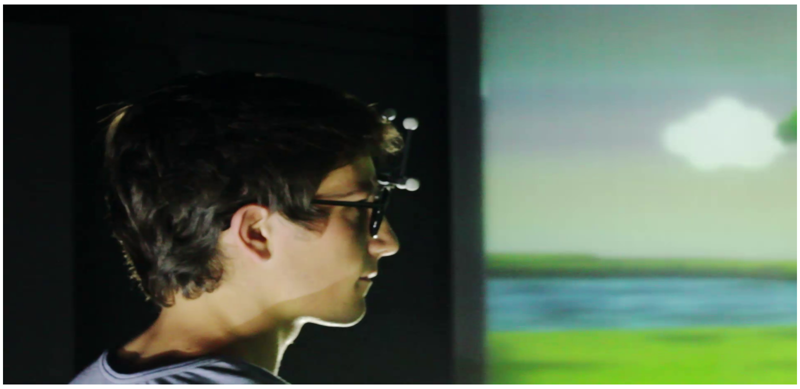


Figure 5.13: This figure shows a participant using the 3D glasses necessary for using the Vision Space in 3D Mode.

Oculus Rift Development Kit 1

The Oculus Rift Development Kit 1 (Oculus) prototype required a special build of the Butterfly mini game using the Oculus SDK. The changes to the game involved the creation of two Oculus cameras: one to handle the terrain, feedbacks and butterflies; and another to control the display of the 3D arm which the player manipulated through one of the candidate tracking devices. The GUI for the game also had to be changed due to limitations with current Oculus SDK. In this regard, the output of the GUI was saved to a special texture and this, in turn, was applied to a cube, which gave the impression of the GUI floating in front of the users face when wearing the HMD.

Figure 5.14: This figure shows the Oculus being used by a participant to play the Butterfly Game.

5.7. Moodle Site

To collaborate with patients and medical staff, an online learning site was created and modified. This would allow the users to participate and complete the user testing in their own time and from any location. The site was created through the use of the eLearning environment Moodle. It was modified with the help of themes, plugins and SCORM for testing serious games created in Unity3D.

Figure 5.15: Ghost Moodle Site Homepage

The testing site had two courses or main experiments. One was for online testing and another for local user testing. Automatic account creation was set in place for users to gain access to the website. Web security was also implemented to ensure bots and other web threats were avoided.

Local

The local user testing included a demographics form and a timetable showing available time slots for user experiments that the user could book. The course also included questionnaires and forms for the various different experiments involved:

1. Tracking Experiment.
2. Display Experiment.
3. Adherence Experiment.
4. Serious Games Experiment.

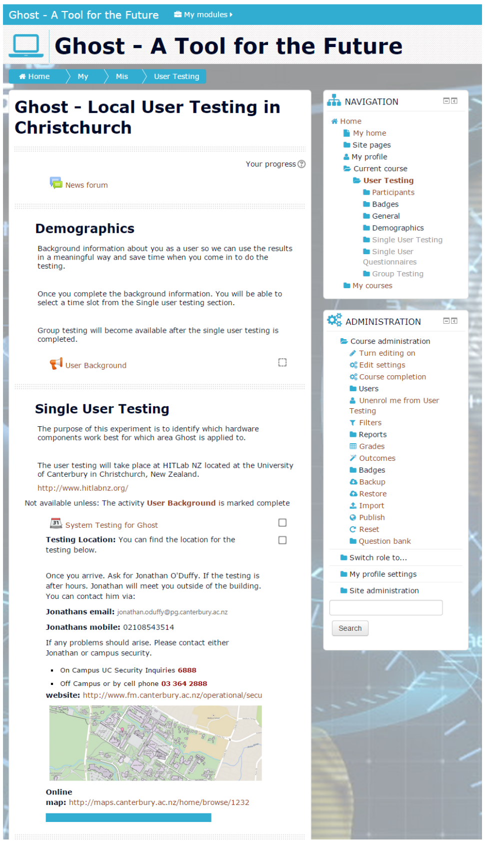


Figure 5.16: Ghost Moodle Site Local User Testing

Online
The online course also had a demographics form but also included other resources not available in the local user testing. It had special builds of certain aspects of the experiments (these are discussed in more detail in the following sub sections). It also had video and images along with a written description in case the online games would not work. This provided the user with four pieces of information which they can then use to answer forms and questionnaires online.

The online course also included badges as a reward mechanism when the user achieved a milestone (i.e. completed certain sections or aspects of the online user testing). The online user testing included the following:

1. Forum for users to collaborate and discuss together online.
2. Questions and Answers Forum to talk to research directly.
3. A News forum to stay up to date with changes in the project.
4. Demographics form.

5. Guidelines and How To section.
6. Adherence Experiment.
7. Butterfly Stroke Experiment.
8. Serious Games Experiment.
9. Medical Data Experiment.
10. Feedback Forms.

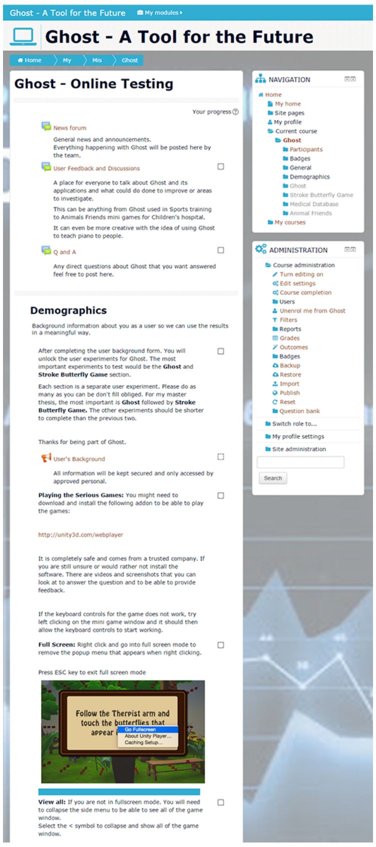


Figure 5.17: Ghost Moodle Site Online User Testing

Each of the experiments had a number of questionnaires that had different number of questions attached to them.

Patient and Therapist

To assist the online user testing, a special build was made from the final prototype of the patient adherence experiment. This version used the mouse as an input device with the help of inverse kinematics over the Kinect V2. It also involved the use of scorm4unity to allow the Unity3D webplayer to be used in the Moodle site.

Butterfly Mini game
To assist the online user testing, a special build was made from the final prototype of the stroke butterfly mini game. This version used the mouse as an input device with the help of inverse kinematics over the kinect v2. It also involved the use of scorm4unity to allow the Unity3D webplayer to be used in the moodle site.

Animal Friends
Special builds of the games designed for the author's prior Parkinson disease research project (Active Arms) was created for use in online user testing. The purpose was to test serious games online to a broad range of different users. This special build used a keyboard and mouse over the custom made mat and the scorm4unity to allow the Unity3D webplayer to be used in the Moodle site. The Moodle site for online user testing was created. It provided all the information contained in its prototypes with additional improvements made on questionnaires and layout based on pilot testing. The local user testing had the questionnaires updated based on feedback and initial investigations. The following figures show the login screen for animal friends, the two games: chicken and marshamllow mini games, and the results table presented to the user upon completing any of the mini games.

(a) Animal Friends Welcome Screen

(b) Marshmallow Mini Game

(c) Results Table

(d) Chicken Mini Game

Figure 5.18: Screenshots of the Animal Friends application used for treating Parkinson Disease

5.8. Equipment

Computer System Information

The computer system used during the user experiments consisted of the following specifications:

Computer System	
Component	Description
CPU	Intel Core i5
Ram	8 Gigs
Graphics Card	GeForce GTX 770
Operating System	64 bit Windows 8.1
Display	NEC LT 265 Projector, Middle projection screen of Vision Space, One Large Mirror

Table 5.5: Computer System used for Experiments

Vision Space System Information
The Vision Space computer was used for two of the display devices (Vision Space 2D and 3D) and had the following specifications:

VisionSpace Computer	
Component	Description
CPU	Intel Core 2 Quad
Ram	8 Gigs
Graphics Card	Three GeForce GTX 260
Operating System	64 bit Windows 7
Display	Six NEC LT 265 Projectors,Three Project Screens, Three Large Mirrors

Table 5.6: Vision Space Computer System used for Experiments

5.9. Summary

In this chapter the author has outlined the Butterfly game that was created based on the research findings for the treatment of upper limb impairment in stroke patients. The process for creating the game was explained in the various software and Unity3d plugins used. The game components that make up the Butterfly Game have been grouped into categories with their purpose explained. Different tracking and display technologies have been supported as variations of the Butterfly Game with the process behind supporting each device explained. Due to the time restrictions faced by therapist and clinicians, collaboration was sought with the creation of a Moodle website. This involved further variations of the Butterfly Game to support online play. The Moodle website was also used to store the results for both online and local user testing as part of the Ghost project.

6. Evaluation

6.1. Evaluation

Participants
To evaluate the tracking, display and construct prototypes described in Chapter 5, it would be ideal to test with the target user group (therapists and patients). However, this was not possible due to the challenges faced in recruiting patients for research, and the time constraints faced by medical staff. As a result, two evaluation approaches were taken:

1. **Local Testing -** Healthy participants were recruited from around the Christchurch area to test the prototypes. The advantage of this approach lies in healthy participants helping to eliminate potential problems before testing is conducted with patients. If a healthy participant found a condition to be difficult to use, the effects would be multiplied for non-healthy individuals: in our case, stroke patients.

2. **Online Component -** Although not a part of the hands-on testing of the tracking, display and construct configurations in the Ghost project, this component allowed medical staff, patients, and users with varying backgrounds to participate in online Ghost experiments regardless of location.

Evaluation Method
In order to test the effectiveness of each tracking and display prototype configuration, a method of evaluation is required. For the **tracking and display** prototypes, we can compare each condition by:

- Game completion time.
- Ranking.
- System Usability Scale (SUS) [97].

- Likert scales [98].

In addition to the above, we can also use observations and interviews to analyze further the effectiveness of each condition. With effective experimental design providing sufficient statistical power, each condition can be compared to determine if the effectiveness between approaches is statistically different.

For the **interaction constructs** in the patient and therapist prototypes, we can compare Game competition time. Observations and interviews also provide further insight into the effectiveness of the patient and therapist prototypes. In addition to analyzing the prototypes, Likert scales were used to gain feedback on the special effects used in the 3D arms. This allows the special effects to be compared against each other.

For the **serious game**, we used Likert scales and Qualitative feedback(comments). Observations and interviews were also used to find the strengths and weaknesses of the various Game Components. Each Game component was broken into different categories depending on their role and compared against each other.

6.2. Prototype Evaluation Questions

Prototype Evaluation Questions		
	Key Terms	**Question**
Tracking	**Accuracy**	Test each tracking solution in terms of accuracy.
	Limitations	Find the limitation of each tracking solution.
	Ease of Use	How easy was each of the tracking method to use?
	Level of Enjoyment	Which methods of tracking provided the most enjoyment?
Display Systems	**Sense of Presence**	This can be defined as much the user feels immersed in the virtual world.
	Cybersickness	This is defined as how well the user can navigate and view the world without suffering from motion sickness.
	Ease of Use	How easy was each of the display method to use?
	Level of Enjoyment	Which methods of display provided the most enjoyment?
Interaction Constructs	**Interaction Constructs**	What are the best methods for having instructions/commands followed?

Table 6.1: Prototype Questions Part 1

Serious Games	**Enhanced Gameplay**	What components of the game enhanced the experiences for the user?
	Depth Perception	What components of the game help with depth perception?
	Gameplay Mechanics	How did various components in the game fulfil their role?
	Performance Feedback	How did various components in the game provide performance feedback?
	Fun	Was the game fun and what was good and bad about it?

Table 6.2: Prototype Questions Part 2

6.3. Experiment Design

The following sections present the design and structure that formed the basis of all experiments in the Ghost research project. The objective of these experiments is to answer the research questions defined in Chapter 3.

Since the current project reported herein represents the first phase of the Ghost development program, the design of experiments was aimed at simulating a stroke rehabilitation exercise based on reaching tasks. However, the results of these experiments may be effective in establishing a benchmark for what healthy people can perform within these experimental conditions and thereby provide a set of performance levels for rehabilitation patients to achieve using the same equipment, constructs and games.

The rehabilitation exercise was based on the Butterfly game outlined in Chapter 5. Each experiment tested different conditions with either a random order or balanced alternating order approach. This was used to negate any learning effect. The experiment recruited healthy individuals from various backgrounds due to the difficulties in recruiting patients and therapists. Again, the reasons for this approach are outlined below:

1. **Availability -** Access to stroke patients or therapist is difficult due to three reasons:

    a) **Health Board:** Access to patients for testing medical equipment or treatment requires strict process reviews due to the sensitive nature involved.

    b) **Time constraints:** Therapist face a growing demand in their profession which results in limited availability.

    c) **Hospitals:** Have limited resources and while they seek solutions they might not be in a position to pursue or help due to the increase in demand in the healthcare sector.

A total of 36 participants were recruited, 24 male (66%) and 12 female (33%), with an average age of 27 years (between 18 to 43 years old). A within subjects design was chosen, allowing all participants to test all the conditions in each experiment. The reach target locations chosen for the experiments are outlined in Chapter 5.

A time limitation of 210 seconds for each condition was imposed for each condition. Pilot tests showed that this time limit should be more than adequate for most participants. If any participant went beyond this time limit placed, the researcher would end the experimental condition and ask the participant fill-out the relevant questionnaire before proceeding onto the next condition to be tested. Participants were not made aware of the time limit placed unless they approached 210 seconds.

Participant Details
Participants were recruited for the experiment from around the Canterbury region. An initial demographics questionnaire section completed by the participants prior to the experiment reported the following characteristics:

1. **Handedness:** Right Handed 33, Left Handed 3.
2. **Prior Experience in experiments:** 31 of 36.
3. **Prior serious games experience:** 27 of 36.
4. **Comfort with technology:** 4 neutral, 12 comfortable, 20 very comfortable.
5. **Prior experience with training systems:** 18 never, 5 once, 12 few times, 1 frequently.

Experimental Variables

To reiterate, the independent variables for the Ghost experiments are the combination of display and tracking approaches and representational/interaction constructs.

The dependent variables include:

1. Task completion time: There are 10 reach targets (Butterflies) that appear one at a time which the participant must collect to finish the game.
2. Ranking of tracking conditions.
3. System Usability Scale(SUS).
4. Likert Scale [98].
5. Qualitative Observations.
6. Qualitative from interviews.

Apparatus and Procedures
The following materials were used to carry out the experiments:

1. Vision Space Theatre.
2. A Desk and Chair.
3. Tracking Prototype systems.
4. Information Sheet and Consent Form (can be found in the Appendix section).

Participants were asked to complete questionnaires after each condition in the experiment. These questionnaires are shown in Appendix section. Participants were given practice time at the start of each condition. This was done to allow participants to become familiar with the system before testing began. Participants were also provided with an overview of each condition and how the apparatus works to further help their understanding of the system.

Experimental Process
The process of the experiments was as follows:

1. The Participant was greeted and brought to the VisionSpace Theatre.

2. The Participant was asked to create an account for the Ghost Moodle site in order to access questionnaires for the experiments.
3. An information sheet and consent form were presented to the participant in order to provide information about the experiment and get their written consent.
4. The Participant proceeds to test the condition selected by the researcher.
5. The Participant has practice time with the condition until they were comfortable in how it operates.
6. The Participant proceeds to play the serious game and catch 10 butterflies in order to complete the game.
7. The Participant is asked to complete the relevant questionnaire.
8. The Participant repeats steps 4-7 , until all the conditions have been tested.

This process is followed until all conditions have been tested by the participant. The random order of the conditions ensured that there was no/reduced learning effects associated with the experiment results.

7. Experiment 1: Tracking Evaluation

In this chapter, the researcher presents the results from tracking experiments conducted to compare different forms of input device. These results include: observations, interviews, questionnaires and statistical information relevant to the experiment.

7.1. Evaluation Goals

The primary goal for this experiment was to compare different forms of input devices that could be used for stroke rehabilitation with a focus on determining the accuracy, cost and ease of use of each of the approaches.

The research hypothesis is: *There is a difference in performance or usability between different input devices.*

The null hypothesis is: *There is no difference in performance or usability between different input devices.*

7.2. Equipment

Tracking Devices Information
The tracking devices for input into the system are the following:

Tracking Devices
Logitech Mouse
Kinect Version 1 Xbox 360
Kinect Version 2 Xbox One
Myo Armband Consumer Version
Flock of Birds from Ascension

Table 7.1: Tracking Devices

Display Devices Information The display device used for output from the system are the following:

Display Devices	
Device	**Description**
Large Display	Middle Screen of VisionSpace

Table 7.2: Display Devices

7.3. Experiment Design

The experiment design used is based on the experiment designed outlined in Chapter 6.3. The following subsections(6.3.1 - 6.3.4) were modified from those outlined in Chapter 6.3 for this experiment:

1. **Participants -** The same Thirty-Six(36) participants as reported in Chapter 6.
2. **Measurements -** The measurements were the same as outlined in Chapter 6.2. Note that in this experiment the focus was on tracking devices rather than display devices, therefore, the same display device was used across all of the tracking variables.

3. **Apparatus and Procedures -** The same material and procedures were used as outlined in Chapter 6.3.3.

4. **Experimental process -** The same process for the experiment was used as outlined in Chapter 6.3.4. The only difference being the use of a single Display Devices in order to compare only Tracking Devices.

7.3.1. Pilot Testing

Preliminary pilot testing revealed that the mouse sensitivity and the Myo Armband are both linked together and different users have different preferences for movement sensitivity between the tracking device and the movement of the virtual arm on the screen. Based on this preliminary exploration a sensitivity setting was selected that most users found acceptable.

The Flock of Birds, Kinect V1, Kinect V2 and DTrack all have a range or means of inputting limb movement into moving the visual constucts to capture the target. For all systems a marker was placed on the ground to provide a rough indication on where to stand during the experiments. This marker acted as a rough guide for each participant due to the nature of varying heights and arm lengths amongst users. So tall users needed to stand further back with short users standing closer to the VS screen. During the practice sessions for each device, the user would find the most comfortable spot for them before the experiment began.

DTrack system was used in the pilot testing stages of the tracking experiment. But due to technical difficulties, it was unable to become operational again during the main part of the tracking experiment. Based on pilot testing results, it appeared to be the most favoured alongside Kinect V2.

The Flock of Birds was also found to sometimes not connect to the Raspberry Pi. The solution to this was to arrive in early, turn on the Flock of Birds first and then turn the Raspberry Pi on to communicate with it. If a connection didn't happen, the systems were turned off and repeated. No problems were had during the tracking experiment.

7.4. Results and Analysis

7.4.1. Results

From analyzing the results gained from the tracking experiment, we can measure the performance of each tracking device. Overall it was found that the Kinect Version 2 provided the fastest completion time and was also the device that users most preferred from the different tracking devices.

7.4.2. Statistical Results

This section will present and analyze the results from the experiment. All 36 participants completed all five tracking conditions. No participants were removed from the data collection or analysis. Statistical significance was accepted at $p < .01$ by dividing p level of .05 by number of conditions.

Completion Time
Figure 7.1 graphs a summary of the mean and standard deviations of the total time required to complete the games across all tracking conditions. Since all participants played the same versions of the games, with the same task (collection of 10 butterflies), this Figure provides a good summary of the total effort required across all tracking devices in completing a game with them as a means of input.

The devices had the following completion times:

- **Mouse -** Took an average of 36.59 seconds with 36 participants having used one before.
- **Kinect -** V1 Took an average of 38.65 seconds with 23 participants having used one before.
- **Kinect -** V2 Took an average of 30.31 seconds with 11 participants having used one before.
- **Myo Armband -** Took an average of 155.20 seconds with 5 participants having used one before.
- **Flock of Birds -** Took an average of 47.29 seconds with 3 participants having used one before.

Analysis of the mean data shows that the Kinect V2 had the fastest completion time, followed by the mouse and Kinect V1. The Flock of Birds completion time was not too slow compared to the previous three tracking devices, but the Myo Armband was by far the slowest being five times slower than the Kinect V2.

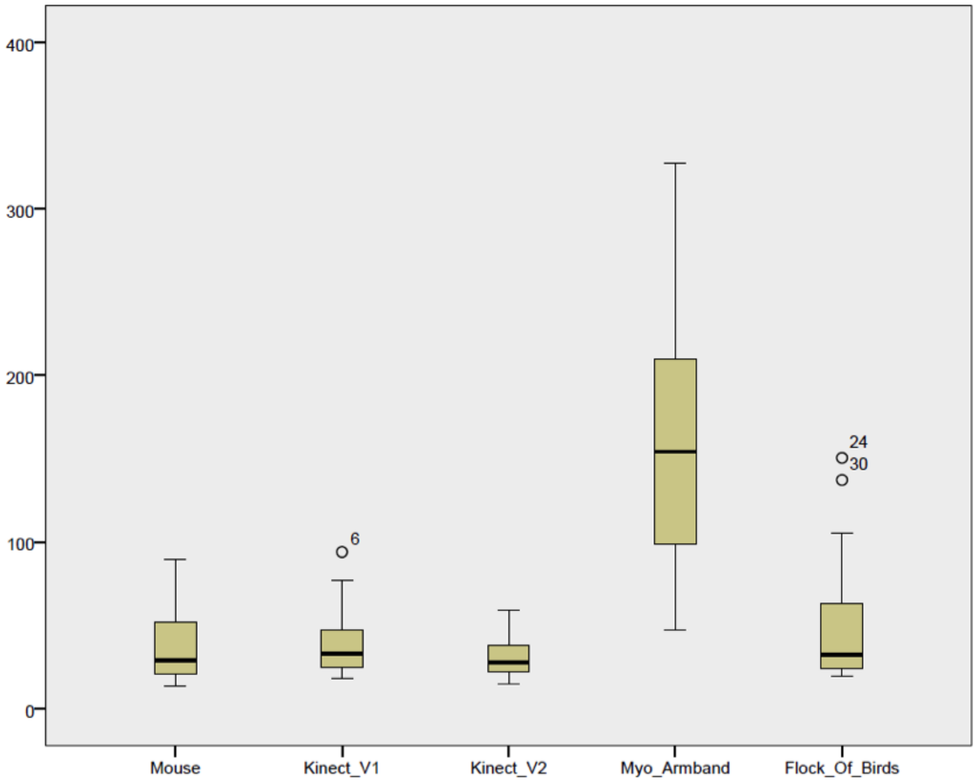


Figure 7.1: Total Game Completion Time for each Tracking Condition

Analysis of variance with repeated measures was used to test for significance across the different tracking devices. It was found that the tracking conditions were not normally distributed, as assessed by Shapiro-Wilk's test ($p > .05$). Pairwise comparisons were performed (using SPSS, 2012) with a Bonferroni correction for multiple comparisons. Statistical significance was accepted at the $p < .01$ level. Task performance in the different tracking conditions was statistically significantly different amongst the tested tracking devices, $2(4) = 76.999$, $p < .0005$. Post hoc analysis revealed statistically significant differences in tracking conditions from Kinect V2 ($M = 30.31$, $SD = 10.58$) to Myo Armband ($M = 155.20$, $SD = 65.38$) ($p < .0005$), Kinect V1 ($M = 38.65$, $SD = 17.93$) to Myo Armband ($p < .0005$), Flock of Birds($M = 47.29$, $SD = 32.71$) to Myo Armband ($p < .0005$) and Mouse ($M = 36.59$, SD 19.12) to Myo Armband ($p < .0005$). There was no other tracking devices comparisons which showed significant results. This showed that the Myo had the slowest task performance time, and that there was no significant difference between the other input devices.

Pairwise Comparisons

Measure: TrackingConditons

(I) Time	(J) Time	Mean Difference (I-J)	Std. Error	Sig.[b]	99% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
Mouse	Kinect V1	-2.061	3.379	1.000	-14.195	10.073
	Kinect V2	6.281	3.526	.836	-6.382	18.944
	Myo	-118.608*	10.578	.000	-156.596	-80.620
	Flock	-10.706	4.839	.336	-28.084	6.673
Kinect V1	Mouse	2.061	3.379	1.000	-10.073	14.195
	Kinect V2	8.342	3.222	.139	-3.229	19.913
	Myo	-116.547*	10.230	.000	-153.285	-79.809
	Flock	-8.644	5.592	1.000	-28.726	11.437
Kinect V2	Mouse	-6.281	3.526	.836	-18.944	6.382
	Kinect V1	-8.342	3.222	.139	-19.913	3.229
	Myo	-124.889*	10.360	.000	-162.094	-87.684
	Flock	-16.986	5.110	.021	-35.336	1.364
Myo	Mouse	118.608*	10.578	.000	80.620	156.596
	Kinect V1	116.547*	10.230	.000	79.809	153.285
	Kinect V2	124.889*	10.360	.000	87.684	162.094
	Flock	107.903*	10.347	.000	70.746	145.059
Flock	Mouse	10.706	4.839	.336	-6.673	28.084
	Kinect V1	8.644	5.592	1.000	-11.437	28.726
	Kinect V2	16.986	5.110	.021	-1.364	35.336
	Myo	-107.903*	10.347	.000	-145.059	-70.746

Based on estimated marginal means

*. The mean difference is significant at the

b. Adjustment for multiple comparisons: Bonferroni.

Figure 7.2: Pairwise Comparison of the different Tracking Conditions Completion Time

Ranking Results by Participants

Participants ranked the devices in order of their preference. There was a significant difference in perceived ranking across the conditions. The Kinect V2 was thought to be significantly better than the Mouse and Myo.

A Friedman test was run to determine if there were statistically significant differences in the rankings between tracking conditions . Pairwise comparisons were performed (SPSS, 2012) with a Bonferroni correction for multiple comparisons. Statistical significance was accepted at the $p < .01$ level. There was a significant difference in the rankings between the different tracking conditions, $2(4) = 76.999$, $p < .0005$. A post hoc analysis revealed statistically significant differences in tracking conditions between the Kinect V2 (M = 1.72, SD = 1.12) and Mouse (M = 3.31, SD = 1.16) ($p < .0005$), Kinect V2 and Myo Armband (M = 4.75, SD = 0.77) ($p < .0005$), Kinect V1 (M = 2.20, SD = 1.01) and Myo Armband ($p < .0005$), Flock of Birds (M = 2.93, SD = 1.24) and Mouse ($p < .0005$) and between Mouse and Myo Armband ($p = .001$). There was almost a significant result with Kinect V2 to Flock of Birds ($p = .012$) and Kinect V1 to Mouse ($p = .065$) but no other tracking devices comparisons which showed significant results. Thus the Kinect V1 and V2 devices were thought to be significantly better to use than the Myo or Mouse, and the Myo was felt to be the worst device to use.

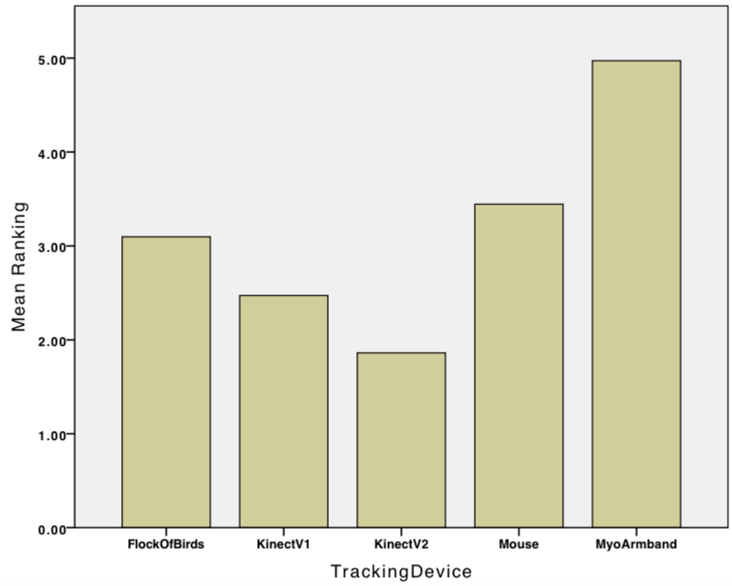


Figure 7.3: Total Ranking for each Tracking Condition

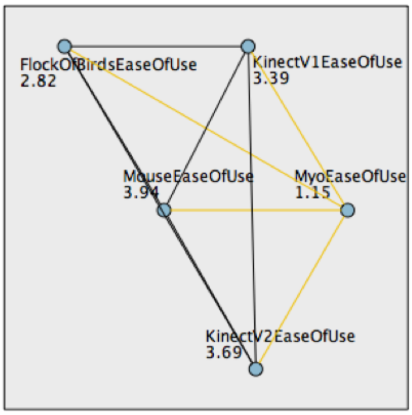
Likert Results

The Likert results in this section were rating the arm conditions based on different roles. The scales ranged from 1 to 5. Further information on the Likert scales used can be found in the Appendix section. The results are as follows:

1. **Ease of Use**
   After completing each condition participants rated the device they were using in terms of Ease of Use. The Likert scale ranged from 1 to 5, where 1 = "Very Difficult", and 5 = "Very Easy". Analysing these results, there was

a significant difference in perceived ease of use across the conditions. The Myo was thought to be significantly worse than the Mouse, Kinect V1 and V2, and Flock of Birds.

Pairwise Comparisons



Each node shows the sample average rank.

Sample1-Sample2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj.Sig.
MyoEaseOfUse-FlockOfBirdsEaseOfUse	-1.667	.373	-4.472	.000	.000
MyoEaseOfUse-KinectV1EaseOfUse	-2.236	.373	-6.000	.000	.000
MyoEaseOfUse-KinectV2EaseOfUse	-2.542	.373	-6.820	.000	.000
MyoEaseOfUse-MouseEaseOfUse	-2.792	.373	-7.491	.000	.000
FlockOfBirdsEaseOfUse-KinectV1EaseOfUse	.569	.373	1.528	.127	1.000
FlockOfBirdsEaseOfUse-KinectV2EaseOfUse	.875	.373	2.348	.019	.189
FlockOfBirdsEaseOfUse-MouseEaseOfUse	1.125	.373	3.019	.003	.025
KinectV1EaseOfUse-KinectV2EaseOfUse	-.306	.373	-.820	.412	1.000
KinectV1EaseOfUse-MouseEaseOfUse	.556	.373	1.491	.136	1.000
KinectV2EaseOfUse-MouseEaseOfUse	.250	.373	.671	.502	1.000

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is .01.

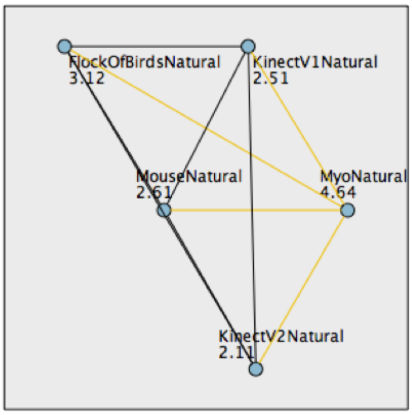
Figure 7.4: Results for Ease of use for Tracking Condition

A Friedman test was run to determine if there were differences in the perceived *"Ease of Use"* across the different tracking conditions. Pairwise comparisons were performed (SPSS, 2012) with a Bonferroni correction for multiple comparisons. Statistical significance was accepted at the $p < .01$

level. There was a statistically significant difference found between amongst the tested tracking devices, 2(4) = 86.318, $p < .0005$. A post hoc analysis revealed statistically significant difference in results between the Myo (M = 1.15, SD = 0.99) and Mouse (M = 3.94, SD = 0.77) ($p < .0005$), Myo and Kinect V1 (M = 3.39, SD = 0.94) ($p < .0005$), Myo and Kinect V2 (M = 3.69, SD = 0.65) ($p < .0005$) and Myo and Flock of Birds (M = 2.82, SD = 1.10) ($p < .0005$). There was almost a significant results with Mouse to Flock of Birds ($p = 0.025$) but no other tracking devices comparisons showed significant results. This shows that the users felt that the Myo was the worst tracking device to use, and that there was no difference in usability between the other devices.

2. **How Natural it was to use**
   After completing each condition participants rated the device they were using in terms of How Natural it was to use. The Likert scale ranged from 1 to 5, where 1 = "Very Natural", and 5 = "Not Natual at all". There was a significant difference in how natural each of the conditions were to use. The Myo was thought to be significantly worse than the Mouse, Kinect V1 and V2, and Flock of Birds.

Pairwise Comparisons



Each node shows the sample average rank.

Sample1-Sample2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj.Sig.
KinectV2Natural-KinectV1Natural	.403	.373	1.081	.280	1.000
KinectV2Natural-MouseNatural	.500	.373	1.342	.180	1.000
KinectV2Natural-FlockOfBirdsNatural	-1.014	.373	-2.721	.007	.065
KinectV2Natural-MyoNatural	2.528	.373	6.783	.000	.000
KinectV1Natural-MouseNatural	.097	.373	.261	.794	1.000
KinectV1Natural-FlockOfBirdsNatural	-.611	.373	-1.640	.101	1.000
KinectV1Natural-MyoNatural	2.125	.373	5.702	.000	.000
MouseNatural-FlockOfBirdsNatural	-.514	.373	-1.379	.168	1.000
MouseNatural-MyoNatural	2.028	.373	5.441	.000	.000
FlockOfBirdsNatural-MyoNatural	1.514	.373	4.062	.000	.000

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is .01.

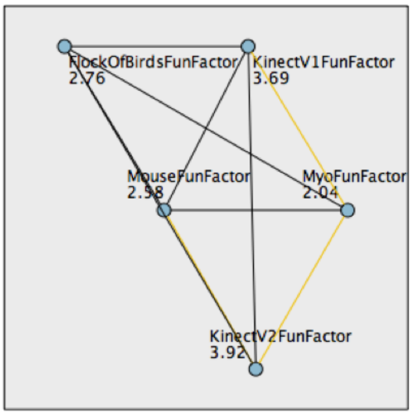
Figure 7.5: Results for How Natural it was to use for Tracking Condition

A Friedman test was run to determine if there were differences in tracking conditions *"how natural it was to use"* during the tracking experiment. Pairwise comparisons were performed (using SPSS, 2012) with a Bonferroni correction for multiple comparisons. Statistical significance was accepted at the $p < .01$ level. There was a statistically significant difference amongst the tested tracking devices, $2(4) = 68.870$, $p < .0005$. A post hoc analysis revealed statistically significant differences in how natural it was perceived to be to use between the Myo ($M = 4.64$, $SD = 0.98$) and Mouse ($M = 2.61$, SD

= 1.12) ($p < .0005$), Myo and Kinect V1 (M = 2.51, SD = 1.01) ($p < .0005$), Myo and Kinect V2 (M = 2.11, SD = 0.83) ($p < .0005$) and Myo and Flock of Birds (M = 3.12, SD = 1.00) ($p < .0005$). There was no other tracking devices comparisons which showed significant results. This shows that the users felt that the Myo was the worst tracking device in term of how natural it was to use, and that there was no difference in naturalness between the other devices.

3. **Fun Factor**
   After completing each condition participants rated the device they were using in terms of Fun it was to use. The Likert scale ranged from 1 to 5, where 1 = "Wasn't fun to use", and 5 = "Really Fun to use". There was a significant difference in perceived fun factor across the conditions. The Myo was thought to be significantly worse than the Kinect V1 and V2 with the Mouse also showing to be significantly worse than the Kinect V2.

Pairwise Comparisons



Each node shows the sample average rank.

Sample1-Sample2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj.Sig.
MyoFunFactor-MouseFunFactor	-.542	.373	-1.453	.146	1.000
MyoFunFactor-FlockOfBirdsFunFactor	-.722	.373	-1.938	.053	.526
MyoFunFactor-KinectV1FunFactor	-1.653	.373	-4.435	.000	.000
MyoFunFactor-KinectV2FunFactor	-1.875	.373	-5.031	.000	.000
MouseFunFactor-FlockOfBirdsFunFactor	-.181	.373	-.484	.628	1.000
MouseFunFactor-KinectV1FunFactor	-1.111	.373	-2.981	.003	.029
MouseFunFactor-KinectV2FunFactor	-1.333	.373	-3.578	.000	.003
FlockOfBirdsFunFactor-KinectV1FunFactor	.931	.373	2.497	.013	.125
FlockOfBirdsFunFactor-KinectV2FunFactor	1.153	.373	3.093	.002	.020
KinectV1FunFactor-KinectV2FunFactor	-.222	.373	-.596	.551	1.000

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is .01.

Figure 7.6: Results for Fun Factor for Tracking Condition

A Friedman test was run to determine if there were differences in tracking conditions textit"how fun it was to use" during the tracking experiment. Pair- wise comparisons were performed (SPSS, 2012) with a Bonferroni correction for multiple comparisons. Statistical significance was accepted at the $p < .01$ level. Tracking conditions was statistically significantly different amongst the tested tracking devices, $2(4) = 51.430$, $p < .0005$. Post hoc analysis revealed statistically significant differences in tracking conditions from Myo (M = 2.04, SD = 1.26) and Kinect V1 (M = 3.69, SD = .50) (p <

.0005), Myo and Kinect V2 (M = 3.92, SD = 0.56) ($p < .0005$) and Mouse (M = 2.58, SD = 1.03) and Kinect V2 (p = .003). There were almost a significant results with Flock of Birds (M = 2.76, SD = 0.85) to Kinect V2 (p = .020) and Mouse to Kinect V1 (p = .029) but no other tracking devices comparisons showed significant results.

SUS Results

A Friedman test was run to determine if there were differences in tracking conditions within System Usability Scale(SUS). Tracking conditions increased from Mouse(Mdn = 76.0) to all other tracking devices(Mdn = 80.0), but the differences were not statistically significant, 2(4) = 7.052, p = .133.

7.5. Qualitative Feedback

The following subsections are categories of the various feedback comments received from participants as part of the tracking experiment. Each subsection is a summary and compression of all the comments given by participants.

Observations There was several repeating anomalies observed during the tracking experiment. They have been labelled with their corresponding meaning.

1. **Extreme Butterflies -** It was observed that butterflies on the far sides of the screen were the most difficult to catch and where participants were getting stuck. It was also noted that butterflies (reach targets) at 80% were the most difficult to catch due to the depth alignment required of the hand position compared to butterflies at 90% reach were the participants hand was almost fully extended.

   Results from Punch Punch Duck[24] found the most difficult reach to be -45 degrees (far left) and 30 degrees elevation (top) at 90% reach to be the hardest. With 45 degrees (far right) and -30 degrees elevation (bottom) at 80% reach to be the easiest. So in summary, the most difficult reach targets are top left while the easiest are bottom right.

   The difference between healthy users finding 90% reach easier compared to stroke patients with 80% could be due to co-ordination. Stroke patients at 80% are at their full extent and it is the 90% that is stretching and bringing function back into their arms. So a stroke patient who is unable to get a target knows they need to stretch more to be successful compared to healthy patients who need to make sure they are not over or under extending. Interestingly, healthy participants from the authors experiment struggled with reach targets that were highlighted difficult for stroke patients from Punch Punch Duck experiment. This indicates that it might not be user error alone with the reach targets but a limitation of the technology. Further research would be needed to investigate this further.

For catching butterflies, there was several strategies adopted by the participants:

1. **Typical -** The hand begins close to the chest with elbow bent - this is the home position. The hand is then extended to the butterfly position and returns to the home position and the action is repeated for the next butterfly.
2. **Reverse mini map -** The mini map was expected to be used when users got confused about the butterfly depth. Instead, some user's solely focused on the mini-map to move the hand over the butterfly and then looking to the main screen to adjust the height. The intended action was movement in x-axis and y-axis with reference for z. Instead the outcome was movement in x and z with reference to main screen for y-axis. This was the most favoured technique used.
3. **Guide back technique -** It was expected that users would move their hands in x and y and catch the butterfly on forward z movement. Instead users extended to the full amount in z-axis and guided in x-axis and y- axis to location. They would then move the hand back in the z-axis but coincident with the x-axis and y- axis to catch the butterfly on the way back to their chest.
4. **Circle technique -** Participants would focus on guiding the shadow cursor of the arm to the shadow cursor of the butterfly located on the ground for position in x-axis and z-axis while focusing on y-axis at the same time.
5. **Liner Render -** Participants would follow the connecting line between the hands position to the butterflies position.

7.5.1. Participants Feedback on Conditions

Mouse Feedback		
	Feedback	**Comments**
Positive	It's easy to use; what participants are used to and that they find it natural to use.	*"Most natural and easiest as i grew up with it."* *"Guess because I am too use to using a mouse so playing that one was natural."* *"More natural but not for this."* *"Used regularly now, we need a change - its more a culture thing."*
Negative	It's a cultural thing to use a mouse - this might be why people find it natural to use. It's an old system and they find it an annoyance to use.	
Observations	Mouse sensitivity needed to be adjusted. Participants got stuck on extreme butterflies; They also used reverse mini map technique, circle technique and guide back technique. In some cases, the hand collider had to be reminded and mini map pointed out to help with depth.	

Table 7.3: Mouse Feedback

Kinect V1 Feedback		
Feedback		**Comments**
Positive	It was easy to use and felt comfortable using it.	*"I feel more comfortable with my arm on the screen and moving my actually arm. Very in sync."* *"The fact that you can use your natural movements to do stuff. Preferred the natural ways of doing something compared to use a device or something."* *"More easy to catch the butterflies."*
Negative	No negative feedback was given.	
Observations	Users got stuck on extreme butterflies and tracking got lost due to participant proximity to the Kinect V1 - users with long arms reaching high reach tasks lost. Some participants used a swatting gesturing, similar to that used by a cat pawing at a fish tank, for catching butterflies.	

Table 7.4: Kinect Version 1 Feedback

Kinect V2 Feedback		
Feedback		**Comments**
Positive	It was natural to use and was comfortable using it; They found it fun, responsive and increased sense of immersion with the serious game; They also found it the simplest solution to use. Some Participants did report that they found no difference between Kinect V2 and Kinect V1.	*"Fun to use and accurate and natural."* *"Just no hardware on my body and pretty natural. Hand in and out."* *"Because you didn't have to hold anything. Was like you were doing it yourself."* *"Found it a bit lag in some ways."* *"Feels more natural and tracking the arm and had a stronger connection between my own arm and what was happening on the screen."*
Negative	Some users reported the feeling of lag or slight delay in use.	
Observations	Some participants leaned and moved closer to the screen when stuck on a butterfly. The reverse mini map technique was used and some participants employed big swiping gestures to catch butterflies - moving up and down in a linear motion over the same butterfly. Tracking was also lost when one user removed his jumper which was strange. His jumper needed to be put back on for the Kinect V2 to detect him.	

Table 7.5: Kinect Version 2 Feedback

Myo Armband Feedback			
Feedback		Comments	
Positive	No positive feedback was given from using the Myo Armband.	*"Hate the butterfly as its right there but I can't get it"* *"Thank God not my real arm"* *"Not really intuitive. never do this movements in the real world."* *"Hard to distinguish between tracking and which was experience part. Didn't like the contour of the my. Felt like bring arm forward and back. Don't know why. Can be good for throwing a grenade or certain situation or combination with tracking systems. Like a helper system / controller but not as a pointer or mouse controller."*	
Negative	Participants felt physical pain when implementing gestures. It broke immersion and was difficult to use; Participants also reported that it was frustrating, not intuitive, struggled to use it, it has a steep learning curve and that they hated it. One feedback was given that it could be a helper system with another tracking device but not standalone.		
Observations	Majority of participants would end up in strange positions and contorted bodies similar to yoga poses. That Myo gestures would not work for everyone and a few participants could not complete the serious game. There was some participants who exceled at using the device but they didn't like it; Reposition of the arm was done for most participants. Negative comments and frustration was common. With one participant, the gestures performed by the user was causing the option gesture command to activate. It was also commented by users during the practice time that their game completion time will be slow on this device.		

Table 7.6: Myo Feedback

Flock of Birds Feedback			
Feedback		**Comments**	
Positive	Was easy to use and responsive. It was interesting and had tactile feedback - was holding something in their hand.	*"Like the Wii."* *"Felt most response. Quick to respond to arm movements and more accurate."* *"Not first preference as have not done stuff like that. Rather new to me. Rather go with something I was comfortable with."*	
Negative	Struggled to use the device and a new method of interaction.		
Observations	Participants got stuck on extreme butterflies; one participant waved frantically like the technique used in wii games with another participant commenting that it was similar to the wii. The mini map seemed to be the main focus as participants found it easier than main screen. One participant also swapped hands during the experiment from right to left.		

Table 7.7: Flock Feedback

7.6. Threats to Validity

Participants with experience with particular tracking devices in the experiment may have influenced the tracking performance of those participants. An analysis of this particular confound was not conducted.

Participants commented that the value of 3 on the Likert scale represents a value and not neutral in feedback. The Likert scale was only labeled on extreme ends(1 and 5).

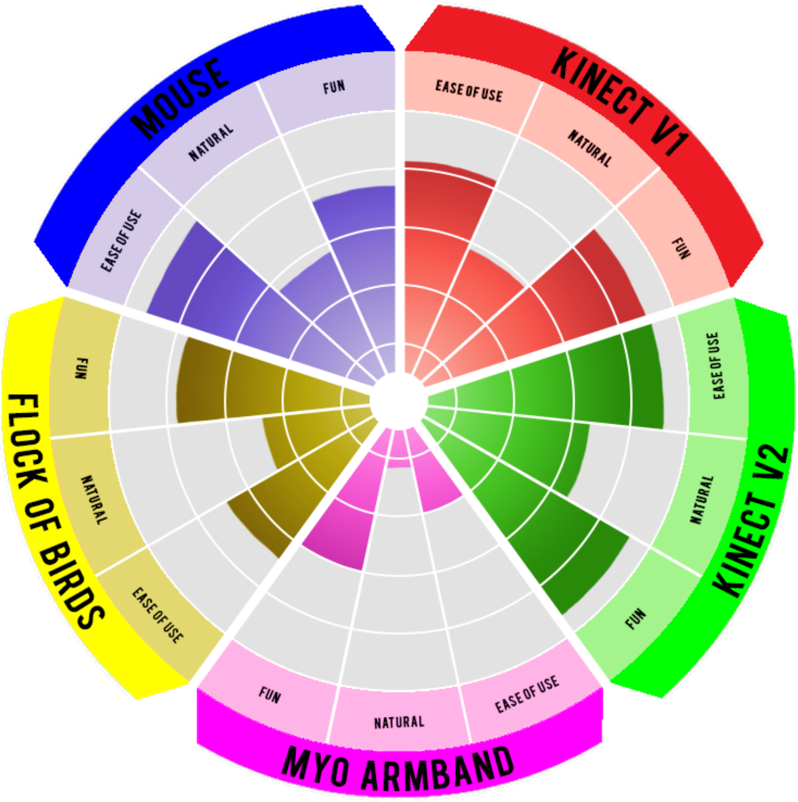
7.7. Discussion of Results

7.7.1. Statistical Summary

The statistical analysis of the conducted tracking experiment results show that the Kinect V2 had the fastest completion time compared to the other tracking devices. It was also the most favoured tracking device in participant ranking. The Myo Armband was the least favoured, consistency coming in last place amongst participant ranking.

The SUS results yielded no significant difference between tracking approaches. However, based on other Likert scale questions, we can determine that the Myo Armband was felt to be the worst device in terms of Ease of Use and How Natural it was to use. In terms of Fun Factor the Myo Armband was also felt to the less fun to use than the other devices. By combining these results with the previous statistics on time and ranking, and with the following results from qualitative feedback, the author asserts that the Myo Armband to be least favored tracking system and the Kinect V1 or V2 to be the most favoured. The Myo Armband does indicate that it has potential but further development would need to be undertaken. The author notes here that due to technical difficulties the DTrack was not evaluated in the main experiment, even though the DTrack did perform well during pilot studies.

The following table shows the mean of Likert results in a radar pie table.



Tracking Likert Results Mean			
	Ease of Use	Natural	Fun
Mouse	4.58	2.71	3.72
Kinect V1	4.16	2.89	4.41
Kinect V2	4.44	3.23	4.55
Myo	2	1.06	3.05
Flock	3.66	2.42	3.80

Figure 7.7: Likert Results Mean

7.7.2. Qualitative Summary

Based on the feedback from the participants we can show that the Myo Armband was the most difficult to use in performing reaching tasks. However, comments from participants highlight that the Myo Armband is heading in the right direction; they just felt it has a lot more work to learn and operate in its current state causing more strain and physical pain.

Participants also found Kinect V1 and V2 to be equivalent in their ultility and performance. The advantage of Kinect V2 is that it provides additional features such as the ability to detect grabbing gestures, speech recognition, heart rate and facial expressions - however these features were not implemented in this experiment and so were not noticed by the participants. These additional Kinect V2 features can all be used in further analysis of patient's performance as they provide additional means of tracking input that can be could be beneficial during rehabilitation exercises.

There was also the mention of using physical devices or props in the game: e.g. a net for catching the butterfly to provide tactile feedback and increase immersion. Although participants also found the mouse natural to use, this could be a by product of frequent use.

Of all the tracking devices, the Kinect V2 emerges as the most preferred for its ease of use and natural movement which increased a sense of immersion. The easy input from the participant into the system via kinect v2 was also found not to break the flow and allowed the participants to focus on the task and not focusing on using the device.

8. Experiment 2: Display Evaluation

In this chapter, the researcher presents the results from the display experiments. These results include: observations, interviews, questionnaires and statistical information relevant to the experiment.

8.1. Evaluation Goals

The primary goal for the experiment was to compare different display approaches and devices that could be used for stroke rehabilitation with a focus on sense of immersion, cost and ease of use.

The research hypothesis is: *There is a difference in performance or usability between different display devices.*

The null hypothesis of: *There is no difference in performance or usability between different display devices.*

8.2. Equipment

Tracking Devices Information
The tracking devices for input into the system are the following:

Tracking Devices
Kinect Version 1 Xbox 360

Table 8.1: Tracking Devices

Display Devices Information The display device used for output from the system are the following:

Display Devices	
Device	**Description**
Large Display	Middle screen of Vision Space
Vision Space 2D	3 screens of the vision space and 3 projectors
Vision Space 3D	3 screens of the vision space and 6 projectors
Head Mounted Display	Oculus Development Kit One

Table 8.2: Display Devices

8.3. Experiment Design

The experiment design used is based on the experiment designed outlined in Chapter 6.3. The following subsections(6.3.1 - 6.3.4) were modified from those outlined in Chapter 6.3 for this experiment:

1. **Participants -** The same Thirty-Six(36) participants recruited for the tracking experiment were recruited again for the display experiment.
2. **Measurements -** The measurements were the same as outline in Chapter 6.2. The only difference being the independent variable being Display Devices over Tracking Devices.
3. **Material and Procedures -** The same material and procedures were used as outlined in Chapter 6.3.3.
4. **Experimental process -** The same process for the experiment was used as outlined in Chapter 6.3.4. The only difference being the use of Display Devices over Tracking Devices being compared.

8.3.1. Pilot Testing

During pilot testing it was revealed that the Oculus builds from Unity3d created two executable files for windows. One being a standard exe file and the other designed specifically for Oculus display mode. But what was found more important was the resolution that the displays were run in. If they resolution was too low, parts of the GUI would overlap: Mini Map being over or behind the Reach Target Number component.

The Vision Space 3D was revealed not to go to the need 6k resolution but being limited to 5k. This prevented 3D mode. The solution around this problem was to run the application in windowed mode and stretch the window to the desired size which allowed for the 3D effect to take place.

The Vision Space was also found to crash during the first pilot testing due to overheating and took 20-30 minutes to fix and relaunch the system. The solution around the problem was to turn off the projectors and only have the running when needed. No problems or crashes happened during the display experiment.

8.4. Results and Analysis

8.4.1. Results

From analyzing the results gained from the display experiment, we can define the performance of each display device. It was shown that, Vision Space 3D was the fastest completion time. While Oculus was the the most preferred display method in the ranking of the different display devices.

8.4.2. Statistical Results

This section will show all the statistical evidence gather from the experiment. In the display experiment, 36 participants completed all four display conditions. No patients were removed from the data collection or analysis. Statistical significance was accepted at $p < .0125$ by dividing p level of .05 by number of conditions.

Completion Time
Figure 8.1 graphs a summary of the mean and standard deviations of the total time required to complete the games across all display conditions. Since all

participants played the same versions of the games, with the same tasks: collection of 10 butterflies; this Figure provides a good summary of the total effort required across all display devices in completing a game with them as a means of output.

The devices had the following completion times:

- **Large Display -** Took an average of 27.64 seconds with 20 participants having used one before.
- **Vision Space 2D -** Took an average of 25.45 seconds with 13 participants having used one before.
- **Vision Space 3D -** Took an average of 24.99 seconds with 16 participants having used one before.
- **Head Mounted Display -** Took an average of 25.40 seconds with 20 participants having used one before.

The mean data shows that the Vision Space 3D had the fastest completion time, followed by the Head Mounted Display and Kinect Vision Space 2D. The Large Display completion time was similar to the previous three display device but was still the slowest out of all the conditions tested.

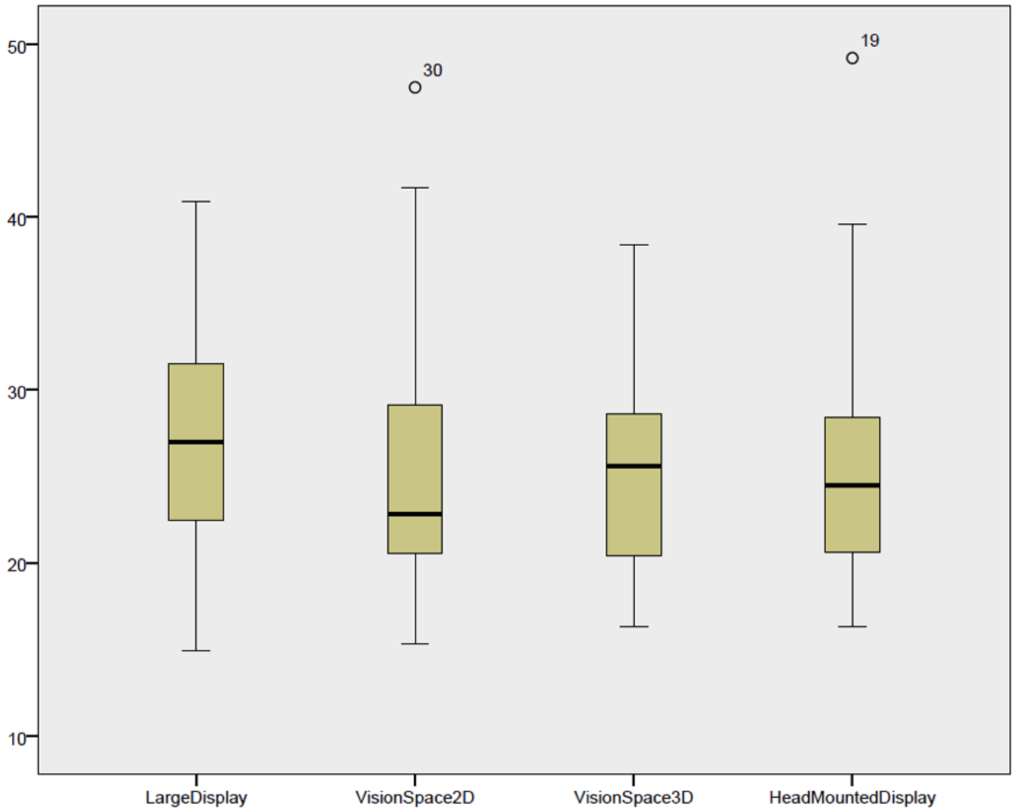


Figure 8.1: Total Game Completion Time for each Display Condition

Analysis of variance with repeated measures was used to test for significance across the different tracking devices. It was found that the tracking conditions were not normally distributed, as assessed by Shapiro-Wilk's test ($p > .05$). Pairwise comparisons were performed (using SPSS, 2012) with a Bonferroni correction for multiple comparisons. Statistical significance was accepted at the $p < .01$ level. Time Completion increased for display conditions from Vision Space 2D ($M = 25.45$, $SD = 7.93$), Head Mounted Display ($M = 25.40$, $SD = 6.96$), Vision Space 3D ($M = 24.99$, $SD = 5.44$) to Large Display ($M = 27.64$, $SD = 6.90$), but the differences were not statistically significant, $2(3) = 3.165$, $p = .367$.

Pairwise Comparisons

Measure: DisplayConditions

(I) Time	(J) Time	Mean Difference (I−J)	Std. Error	Sig.[a]	99% Confidence Interval for Difference[a] Lower Bound	Upper Bound
Large Display	VisionSpace 2D	2.251	1.322	.585	−2.253	6.755
	VisionSpace 3D	2.798	1.462	.383	−2.182	7.779
	Oculus	2.412	1.411	.578	−2.396	7.220
VisionSpace 2D	Large Display	−2.251	1.322	.585	−6.755	2.253
	VisionSpace 3D	.547	1.394	1.000	−4.201	5.296
	Oculus	.161	1.397	1.000	−4.598	4.920
VisionSpace 3D	Large Display	−2.798	1.462	.383	−7.779	2.182
	VisionSpace 2D	−.547	1.394	1.000	−5.296	4.201
	Oculus	−.386	1.271	1.000	−4.715	3.943
Oculus	Large Display	−2.412	1.411	.578	−7.220	2.396
	VisionSpace 2D	−.161	1.397	1.000	−4.920	4.598
	VisionSpace 3D	.386	1.271	1.000	−3.943	4.715

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Figure 8.2: Pairwise Comparison of the different Display Conditions Completion Time

Ranking Results by Participants

A Friedman test was run to determine if there were differences in display conditions ranking by participants during the display experiment. Pairwise comparisons were performed (SPSS, 2012) with a Bonferroni correction for multiple comparisons. Statistical significance was accepted at the $p < .0125$ level. Display conditions were statistically significantly different amongst the tested display devices, 2(3) = 33.070, $p < .0005$. Post hoc analysis revealed statistically significant differences in display conditions from Oculus (M = 1.59, SD = 0.88) and Vision Space 3D (M = 2.66, SD = 1.09) ($p = .004$) and Oculus and Large Display (M = 3.33, SD = 0.97) ($p < .0005$). There was almost a significant result with Oculus and Vision Space 2D (M = 2.43, SD = 0.76) ($p = .042$) and Vision Space 2D to Large Display ($p = .024$) but no other display devices comparisons which showed significant results.

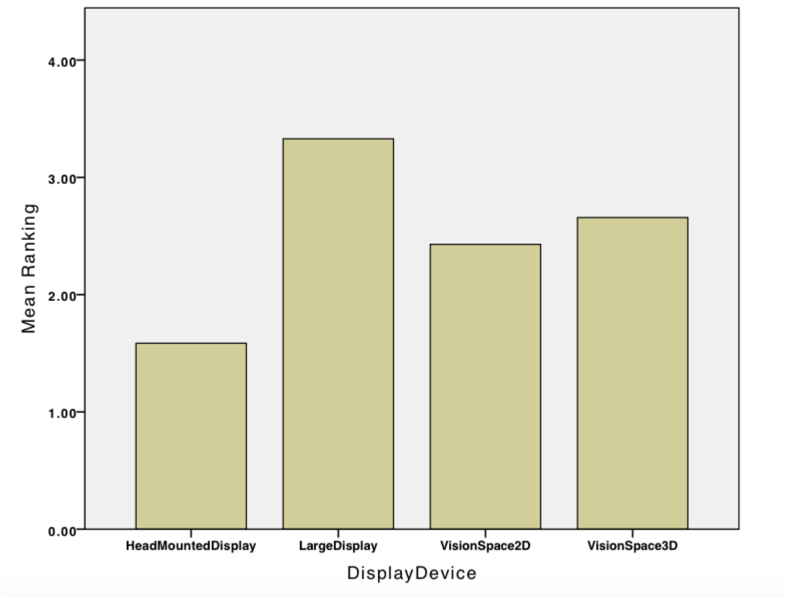
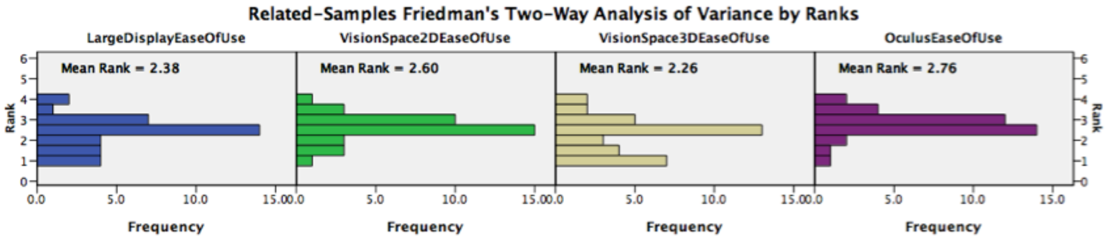


Figure 8.3: Total Ranking for each Display Condition

Likert Results

The Likert results in this section were rating the arm conditions based on different roles. The scales ranged from 1 to 5. Further information on the Likert scales used can be found in the Appendix section. The results are as follows:

1. **Ease of Use**
   After completing each condition participants rated the device they were using in terms of Ease of Use. The Likert scale ranged from 1 to 5, where 1 = "Very Difficult", and 5 = "Very Easy".



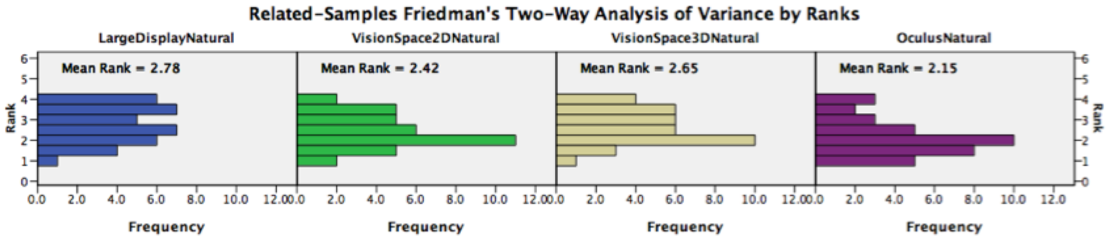
Total N	36
Test Statistic	7.452
Degrees of Freedom	3
Asymptotic Sig. (2-sided test)	.059

1. Multiple comparisons are not performed because the overall test retained the null hypothesis of no differences.

Figure 8.4: Results for Ease of use for Display Condition

A Friedman test was run to determine if there were differences in ease of use across display conditions. Display conditions increased from Vision Space 3D (M = 2.36, SD = 0.79) and Large Display (M = 2.38, SD = 0.61) to VisionSpace 2D (M = 2.60, SD = 0.56) and Oculus (M = 2.76, SD = 0.60), but the differences were not statistically significant, 2(3) = 7.452, p = .059.

2. **How Natural it was to use**
   After completing each condition participants rated the device they were using in terms of How Natural it was to use. The Likert scale ranged from 1 to 5, where 1 = "Very Natural", and 5 = "Not Natual at all".



Total N	36
Test Statistic	8.208
Degrees of Freedom	3
Asymptotic Sig. (2-sided test)	.042

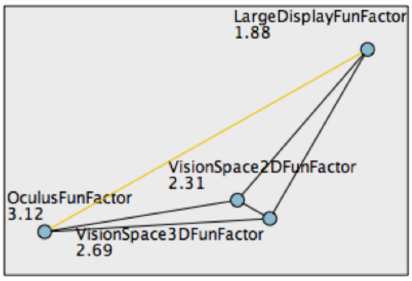
1. Multiple comparisons are not performed because the overall test retained the null hypothesis of no differences.

Figure 8.5: Results for How Natural it was to use for Display Condition

A Friedman test was run to determine if there were differences in display conditions "how natural it was to use" during the display experiment. Pairwise comparisons were performed (SPSS, 2012) with a Bonferroni correction for multiple comparisons. Statistical significance was accepted at the $p < .0125$ level. Display conditions were not statistically significantly $2(3) = 8.208$, $p < .042$.

3. **Fun Factor**
After completing each condition participants rated the device they were using in terms of Fun it was to use. The Likert scale ranged from 1 to 5, where 1 = "Wasn't fun to use", and 5 = "Really Fun to use".

Pairwise Comparisons



Each node shows the sample average rank.

Sample1-Sample2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj.Sig.
LargeDisplayFunFactor-VisionSpace2DFunFactor	-.431	.304	-1.415	.157	.942
LargeDisplayFunFactor-VisionSpace3DFunFactor	-.819	.304	-2.693	.007	.042
LargeDisplayFunFactor-OculusFunFactor	-1.250	.304	-4.108	.000	.000
VisionSpace2DFunFactor-VisionSpace3DFunFactor	-.389	.304	-1.278	.201	1.000
VisionSpace2DFunFactor-OculusFunFactor	-.819	.304	-2.693	.007	.042
VisionSpace3DFunFactor-OculusFunFactor	-.431	.304	-1.415	.157	.942

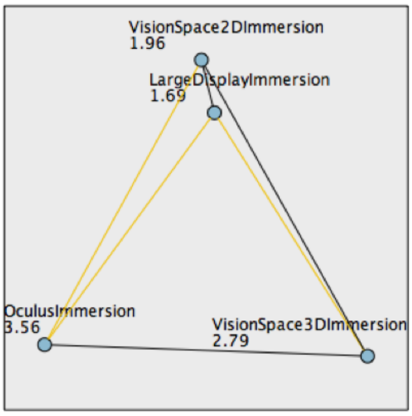
Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is .01.

Figure 8.6: Results for Fun Factor for Display Condition

A Friedman test was run to determine if there were differences in display conditions "how natural it was to use" during the display experiment. Pairwise comparisons were performed (SPSS, 2012) with a Bonferroni correction for multiple comparisons. Statistical significance was accepted at the $p < .0125$ level. Display conditions were statistically significantly different amongst the tested display devices, $2(3) = 33.822$, $p < .0005$. Post hoc analysis revealed statistically significant differences in display conditions from Large Display ($M = 1.88$, $SD = 0.93$) and Oculus ($M = 3.12$, $SD = 0.40$) ($p < .0005$). There was almost a significant results with Large Display to Vision Space 3D ($M = 2.69$, $SD = 0.61$) ($p = .042$) and Vision Space 2D ($M = 2.31$, $SD = 0.73$) to Oculus ($p = .042$) but no other display devices comparisons showed significant results.

4. **Immersion**
   After completing each condition participants rated the device they were using in terms of Immersion. The Likert scale ranged from 1 to 5, where 1 = "Not Very", and 5 = "Very Immersed".

Pairwise Comparisons



Each node shows the sample average rank.

Sample1-Sample2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj.Sig.
LargeDisplayImmersion-VisionSpace2DImmersion	-.264	.304	-.867	.386	1.000
LargeDisplayImmersion-VisionSpace3DImmersion	-1.097	.304	-3.606	.000	.002
LargeDisplayImmersion-OculusImmersion	-1.861	.304	-6.116	.000	.000
VisionSpace2DImmersion-VisionSpace3DImmersion	-.833	.304	-2.739	.006	.037
VisionSpace2DImmersion-OculusImmersion	-1.597	.304	-5.249	.000	.000
VisionSpace3DImmersion-OculusImmersion	-.764	.304	-2.510	.012	.072

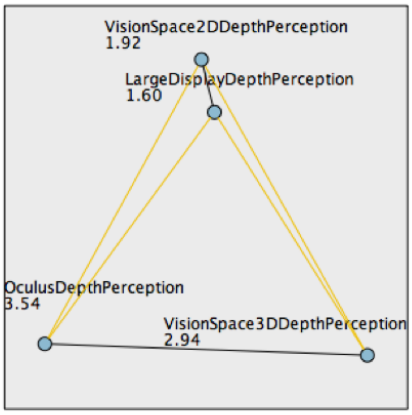
Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is .01.

Figure 8.7: Results for Immersion for Display Condition

A Friedman test was run to determine if there were differences in display conditions for the perceived level of immersion felt during the display experiment. Pairwise comparisons were performed (SPSS, 2012) with a Bonferroni correction for multiple comparisons. Statistical significance was accepted at the $p < .0125$ level. Immersion from display conditions were statistically significant different amongst the tested tracking devices, $2(3) = 58.637$, $p < .0005$. Post hoc analysis revealed statistically significant differences in display conditions from Large Display ($M = 1.69$, $SD = 1.17$) and Vision Space 3D ($M = 2.79$, $SD = 1.12$) ($p < .002$), Large Display to Oculus ($M = 3.56$, $SD = 0.54$) ($p < .0005$) and Vision Space 2D ($M = 1.96$, $SD = 1.25$) to Oculus ($p < .0005$). There was almost a significant results with Vision Space 2D and Vision Space 3D ($p < .037$) but no other display devices comparisons showed significant results.

5. **Depth Perception**
   After completing each condition participants rated the device they were using in terms of Immersion. The Likert scale ranged from 1 to 5, where 1 = "Didn't Help at all", and 5 = "Helped a lot".

Pairwise Comparisons



Each node shows the sample average rank.

Sample1-Sample2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj.Sig.
LargeDisplayDepthPerception-VisionSpace2DDepth Perception	-.319	.304	-1.050	.294	1.000
LargeDisplayDepthPerception-VisionSpace3DDepth Perception	-1.347	.304	-4.427	.000	.000
LargeDisplayDepthPerception-OculusDepthPerception	-1.944	.304	-6.390	.000	.000
VisionSpace2DDepth Perception-VisionSpace3DDepthPerceptio n	-1.028	.304	-3.378	.001	.004
VisionSpace2DDepth Perception-OculusDepthPerception	-1.625	.304	-5.340	.000	.000
VisionSpace3DDepth Perception-OculusDepthPerception	-.597	.304	-1.963	.050	.298

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is .01.

Figure 8.8: Results for Depth Perception for Display Condition

A Friedman test was run to determine if there were differences in reported depth perception across display conditions. Pairwise comparisons were performed (SPSS, 2012) with a Bonferroni correction for multiple comparisons. Statistical significance was accepted at the $p < .0125$ level. Display conditions were statistically significantly different amongst the tested tracking devices, $2(3) = 65.823$, $p < .0005$. Post hoc analysis revealed statistically significant differences in display conditions from Large Display

(M = 1.60, SD = 1.08) and Vision Space 3D (M = 2.94, SD = 1.05) ($p < .0005$), Large Display and Oculus (M = 3.54, SD = 0.72) ($p < .0005$), Vision Space 2D(M = 1.92, SD = 1.21) and Vision Space 3D ($p = .004$) and Vision Space 2D to Oculus ($p < .0005$). There were no other display device comparisons which showed significant results.

SUS Results A Friedman test was run to determine if there were differences in display conditions within System Usability Scale(SUS). All display conditions were the same (Mdn = 80.0) with no differences being statistically significant, 2(3) = 5.463, $p = .141$.

8.5. Qualitative Feedback

8.5.1. Participants Feedback on Conditions

Large Display Feedback		
	Feedback	**Comments**
Positive	What participants are used to. It's easier to use and brings better enjoyment.	"Just seemed easier, less of a barrier." "Felt more something I am use to and it was easier and didn't have to a huge screen and I didn't have to move around. Everything was in perspective." "Large Display least connected to 3D, least special. Wasn't bad, just not as good as the others."
Negative	It's common and not immersive; There was no depth perception and it was boring. Other participants commented that it was ok.	
Observations	Some participants got too close to the screen when stuck on a butterfly. Kinect v1 tracking was lost on some users when their hands went outside the Kinect field of view which in turn caused the tracking of the am to bit affected. One participant had stopped big swipe gestures but returned to that method when stuck on butterflies. Another had no problems with depth perception but was a serious games designer.	

Table 8.3: Mouse Feedback

VisionSpace 2D Feedback		
Feedback		**Comments**
Positive	Peripheral vision and easy on the eyes. There was also the occlusion of the surrounding environment.	"Simple and easy on the eyes. Better than large screen as it surrounds you." "Not much difference between vision space 2D and Large Display. The depth information was missing."
Negative	It's still common like large display and has no depth perception.	
Observations	The side screens could be used more based on feedback. It was viewed as wasted space due to no butterflies spawning there. It was also seen that users when back to using the mini map after 3D - in 3D the mini map was not used. Some participants found the display not as fun after experiencing 3D and noticed the turtle by looking around on the displays.	

Table 8.4: Vision Space 2D Feedback

VisionSpace 3D Feedback		
Feedback		Comments
Positive	Best display and big. It was also not disorientating like the head mounted display and was in 3D.	"3D glasses were good and not disorientating." "Down grade version of Oculus. Why do I have to get this one when I can get that one."
Negative	It's like a 3D movie compared to head mounted display which is real. Felt sick and was blurry from 2D GUI mixed with 3D effects. Double vision was experienced and was viewed as a downgraded version of oculus.	
Observations	Depth perception was provided and participants stopped using mini map; Some participants also noticed turtle; Some participants didn't find it as fun after experiencing the oculus; Popup messages were also disliked in this mode.	

Table 8.5: Vision Space 3D Feedback

Oculus Rift Feedback		
	Feedback	**Comments**
Positive	Had high immersion with the participants feeling like they were in the game. Comments from users included fun, awesome, impressive, cool. Participants also found it useful, had peripheral vision, natural with being able to look around and behind them. Participants found it helpful in catching butterflies as it provided depth perception with no need to use other feedback.	"so cool" "heaps of fun" "really good" "dont want to take it off" "amazing" "felt dizzy" "Most immersive surround and can see behind you and adds to that level of immersion." "Don't like. Cool concept but strains the eyes. The graphics are not that flash yet(resolution)."
Negative	Some participants found the resolution too low.	
Observations	Participants were amazed; They felt immersed, commented on it being really cool and had depth perception. Felt like they were there and the real world was occluded. Some participants also commented on wanting to change feedback given for other display devices after experiencing oculus. Some participants did find looking around disorientating when moving their head. Was also some layering issues commented with hand behind the trees but this is a current limitation of the oculus with development in unity3d.	

Table 8.6: Oculus Feedback

8.6. Threats to Validity

One participant was missing a time score for Large Display. That participants results were removed from the calculations for completion time.

Participants experience with some of the display devices being used in the experiment may have influenced the results on those particular devices.

Participants commented on the Likert scale of being incremental values. They referred to 3 on the Likert having worth and not being neutral. As only the extreme ends of the scale were labeled. They also requested a 7 or 9 point Likert scale so that they can provide a more detailed rating and feedback on display devices.

Participants also commented on wanting to change the feedback given on previous questionnaires, usually after experiencing the Oculus Dk1 as they found the immersion level to be extremely high compared to other display devices.

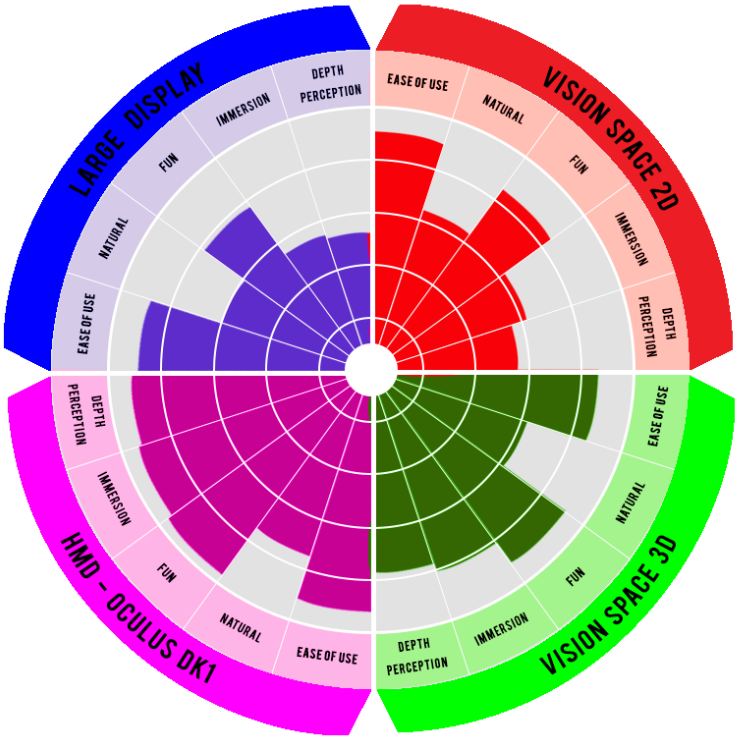
8.7. Discussion of Results

8.7.1. Statistical Summary

From the statistical analysis of task completion times we show that the Vision Space 3D had the fastest completion compared to the other display devices. The Head Mounted Display was the most favoured display device in participant ranking. Of all the display devices, the Large display was the least favoured in participant ranking and also the longest in time completion on average.

The SUS results yielded no system above the others. But based on other Likert scale questions, we conclude that the 3D displays such as the Vision Space 3D and Oculus provide a higher sense of Immersion and Depth Perception. The 2D displays (Large Display and Vision Space 2D) also seem to be less fun. But no display appears to be best at being Natural to use.

The following table shows the mean of Likert results in a radar pie table.



Display Likert Results Mean					
	Ease of Use	Natural	Fun	Immersion	Depth Perception
Large Display	4.44	3	3.94	2.77	2.61
Vision Space 2D	4.52	3.20	4.25	3.08	2.88
Vision Space 3D	4.33	3.09	4.55	4.05	3.91
HMD – Oculus DK1	4.61	3.77	4.80	4.77	4.63

Figure 8.9: Likert Results Mean

8.7.2. Qualitative Summary

Based on feedback from the participants we can show that the Oculus seems to be the most favoured in performing reaching tasks. The Large Display was rated as the lowest but participants highlighted that the ordering does not mean they do not like using the system, it is just an order of preference based on options provided and that the Large Display would be fine to use.

Participants found the Oculus provided a high sense of immersion that allowed them to focus on the reaching tasks and provided the ability to judge depth perception naturally in a way the 2D displays could not. The participants had to rely more on GUI elements and game components to judge depth when using 2D display devices such as the mini map which was not used in 3D display devices but used consistently in 2D display devices. It was also noted by the author that the extreme butterflies that were difficult to catch in the tracking experiment proved less of an obstacle for participants when using 3D displays. This could be due to the depth information provided by 3D display devices compared to 2D displays.

Some participants wanted to change their ranking scores after experiencing the Oculus: to rate it higher amongst the display devices. One participant commented on how the different 3D display devices felt to him saying:

"…the Oculus brought into a new world and feeling part of it, while the Vision Space 3D was the joining of two worlds together, in that it brought the 3D world into the real world."

Participants commented on the 2D display devices, such as the Large Display, as being common and not enhancing the experience in the way Oculus does. But due to it being common, it would be fine to use with no users finding difficulty in working with it.

Participants also commented on the importance of visual field-of-view on reaching tasks. The wide field of view displays such as the VisionSpace and Oculus unlocked the use of peripheral vision and ability to look around for targets not available in the Large Display. This would bring another element of engaging the users in tasks and implement a key feature of these devices.

By combining these results on completion time and ranking with the results that follow from qualitative feedback, we conclude that the Oculus to be the most favoured display system while the Large Display is the least favoured. It should be noted that the Large display is still suitable for rehabilitation based.

9. Experiment 3: Interaction Constructs Evaluation

In this chapter, the author presents the results from the adherence (interaction construct) experiments. This includes observations, interviews, questionnaires and statistical information relevant to the experiment.

9.1. Evaluation Goals

The primary objective for the adherence experiment was to compare different visual representations that could be used for stroke rehabilitation with a goal of determining which methods of therapist and patient visual representations that optimize the ability of users to follow exercise instruction.

The research hypothesis is: *There is a difference in performance or usability between different interaction constructs or special effects.*

With the null hypothesis of: *There is no difference in performance or usability between different interaction constructs or special effects.*

9.2. Equipment

The tracking devices for input into the system are the following:

Tracking Devices
Kinect Version 2 Xbox One

Table 9.1: Tracking Devices

The display devices for input into the system are the following:

Display Devices	
Device	**Description**
Head Mounted Display	Oculus Development Kit One

Table 9.2: Display Devices

The visual effects used for interaction constructs in the system are the following:

Note: all the visual effects shown here will be working with a simulated collaborator who will always have the Real Arm Condition applied to them.

Arm Conditions
Real Arm
Ghost Arm
Occlusion Arm
Colour Depth providing depth alignment information
Ghost Occlusion Arm

Table 9.3: Arm Conditions

(a) Real Arm Condition

(b) Ghost Arm Condition

(c) Occlusion Arm Condition

(d) Colour Arm Condition

(e) Ghost Occlusion Arm Condition

Figure 9.1: Stroke Template Demo

9.3. Experiment Design

The experiment design used is based on the experiment outlined in Chapter 6.3. The difference between the two experimental designs is the use of alternating order instead of random order. This was due to there being two parts(role playing as patient and therapist) to the experiment with each part containing five conditions(visual effects). So the alternating order of which part or role the participant would use first was alternated to ensure a balance approach was taken in the experiment. The number of butterflies required by the participant to catch was increased from 10 to 15 as outlined in Chapter 4.5 Special Effects. The following image shows the butterfly reach locations for the Interaction Constructs experiment:

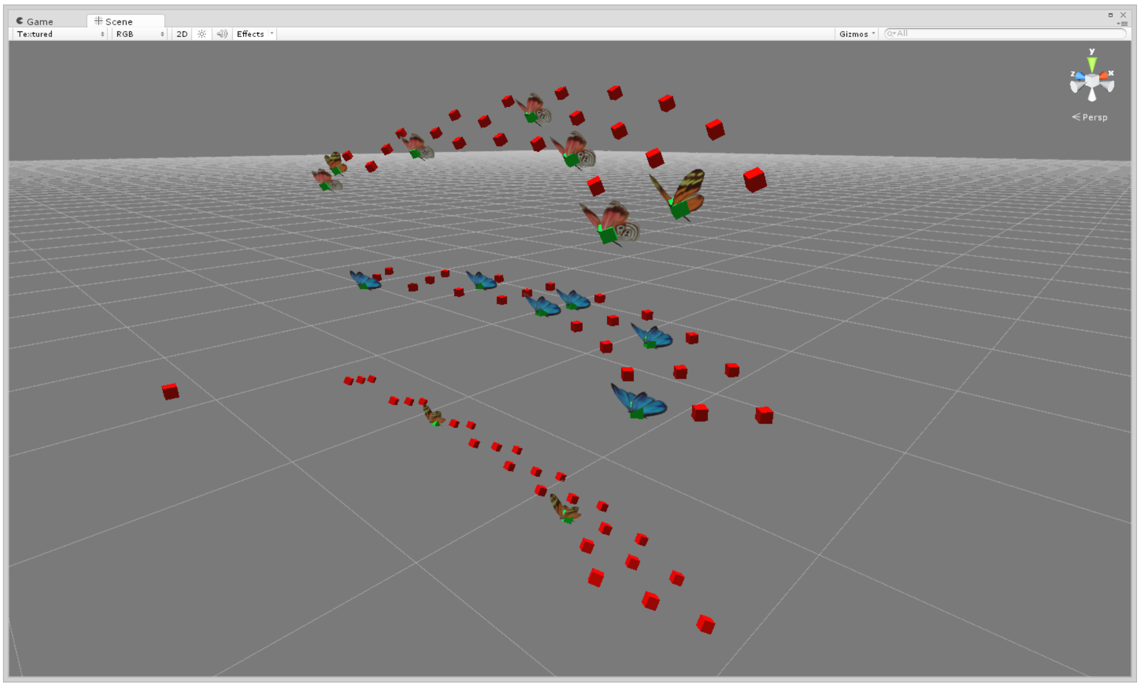


Figure 9.2: 15 Reach Locations

The gameplay for the Butterfly game is different from previous experiments. The difference is the use of another arm in the scene which is controlled by an AI. The term AI in this context refers to a Machine Algorithm which randomly moves the arm based on random reach locations chosen from a list. The arm controlled by the AI always has the real arm visual effect and will play the opposite role that the participant is playing. So in the experiment there is always one arm leading the exercise (therapist) and one arm following (patient). The participant will take turns playing each role, hence two parts to the experiment. The participants 3D arm will also cycle through the selected visual effects as they collect butterflies during the experiment. Further information on how this works is outlined in Chapter 4.5 in the Special Effects, Patient, and Therapist subsections.

The following subsections(6.3.1 - 6.3.4) were modified from those outlined in Chapter 6.3 for this experiment:

1. **Participants -** The same Thirty-Six(36) participants recruited for the tracking experiment were recruited again for the interaction construct experiment.
2. **Measurements -** The measurements were the same as outline in Chapter 6.2; the only difference being the independent variable being the selected Arm Visual Effect over Tracking Devices.
3. **Material and Procedures -** The same material and procedures were used as outlined in Chapter 6.3.3.
4. **Experimental process-** The same process for the experiment was used as outlined in Chapter 6.3.4. The only difference being the independent variables; i.e. comparison of Interaction Construct Games rather than Tracking Devices.

Pilot Testing
Early pilot testing found that for the adherence experiment there was confusion between the online application and local application as one input was via the mouse and another via the Kinect V2. The solution to this problem was fixed by creating a folder called Adherence Experiment with the relevant exe files labelled according.

Another problem identified in the pilot study was the need to create an environment in which the participants could view the arm conditions with better discrimination. To solve this problem, the butterflies only spawn when certain conditions are met. For the Patient part of the experiment, butterflies only spawned once the therapist arm (controlled by AI) stopped moving. This allowed the participant to observe what reach task was next and simply follow the same path as the therapist.

For the Therapist part of the experiment, the roles of the participant were reversed. So to ensure that the participant did not speed through the experiment. Butterflies would only spawn once the patient arm (controlled by AI) reached the location the therapist collected the butterfly at (excluding the initial butterfly). This helped simulate the role of the participant leading a patient through reaching exercises.

9.4. Results and Analysis

9.4.1. Results

From analyzing the results gained from the interaction construct experiment, we can define the performance of each arm condition and role (patient and therapist). It was shown that, the Ghost Occlusion Arm was deemed the best for both patient and therapist roles when working with a real arm visual effect on their collaborator. The fastest completion time among the two roles came from the patient. This was due to it being easier to follow the movements of the other arm then leading. This could be due to the effects associated with action observation treatment and motor imagery.

9.4.2. Statistical Results from Experiment

This section will show all the statistical evidence gathered from the experiment. In the Interaction Construct experiment, 36 participants completed all five arm conditions and two roles. No participants were removed from the data collection or analysis. Statistical significance was accepted at $p < .025$ by dividing p level of .05 by number of roles.

Completion Time
Figure 9.3 graphs a summary of the mean and standard deviations of the total time required to complete the games across all roles. Since all participants played the same versions of the games, with the same tasks: collection of 15 butterflies. The below Figure provides a good summary of the total effort required across the two roles in completing a game depending on their role.

The roles had the following completion times:

- **Patient -** Took an average of 47.22 seconds
- **Therapist -** Took an average of 59.87 seconds

The mean data shows that the Patient had the fastest completion time, followed by the therapist.

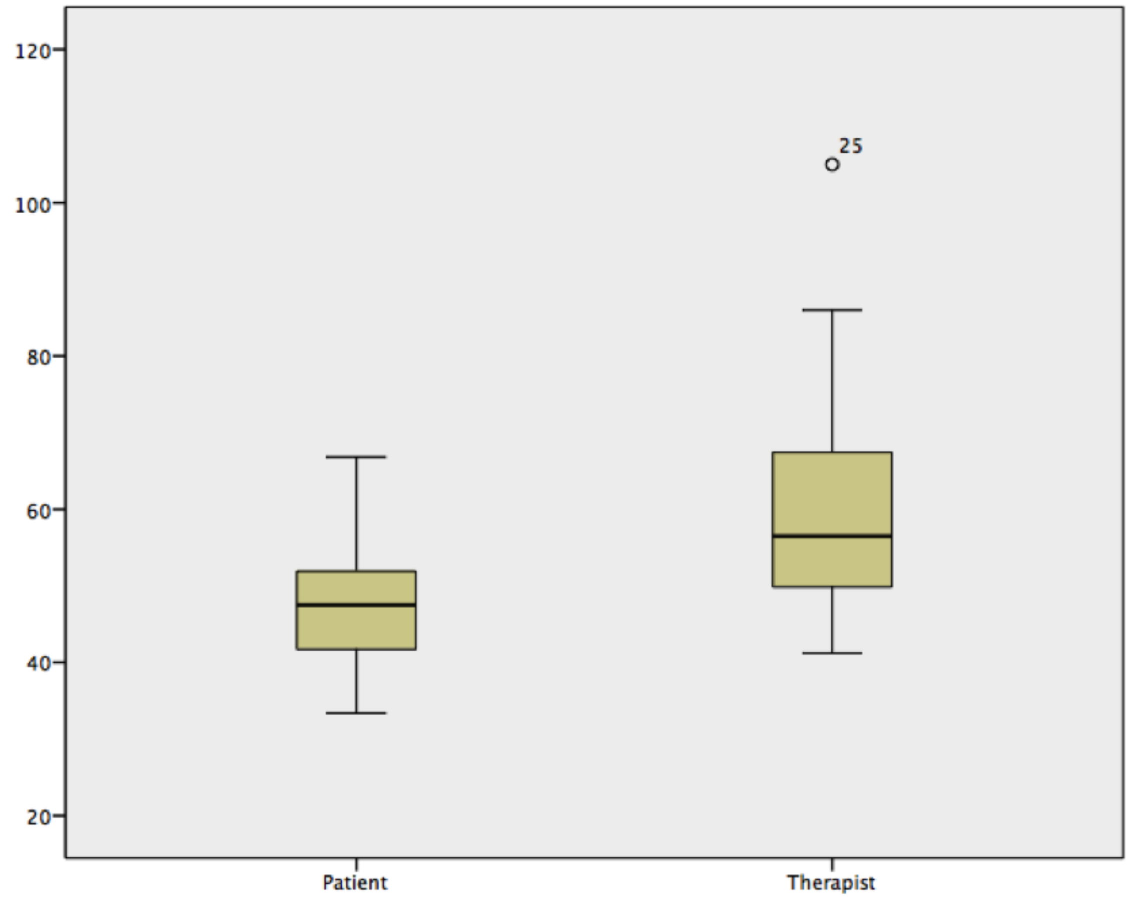


Figure 9.3: Total Game Completion Time for each Interaction Construct Role

Analysis of variance with repeated measures was used to test for significance across the different tracking devices. It was found that the interaction construct roles were not normally distributed, as assessed by Shapiro-Wilk's test ($p > .05$). Pair-wise comparisons were performed (SPSS, 2012) with a Bonferroni correction for comparison. Statistical significance was accepted at the $p < .025$ level. Interaction construct roles was statistically significantly different amongst the tested interaction construct roles, $2(1) = 14.226$, $p < .0005$. Post hoc analysis revealed statistically significant differences in interaction construct roles from Patient ($M = 47.22$, $SD = 9.11$) to Therapist ($M = 59.87$, $SD = 14.99$) ($p < .0005$).

Pairwise Comparisons

Measure: InteractionConstructRoles

(I) Time	(J) Time	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
Patient	Therapist	-12.655*	2.437	.000	-17.632	-7.677
Therapist	Patient	12.655*	2.437	.000	7.677	17.632

Based on estimated marginal means

*. The mean difference is significant at the

b. Adjustment for multiple comparisons: Bonferroni.

Figure 9.4: Pairwise Comparison of the different Interaction Construct Roles Completion Time

Likert Results

The Likert results in this section were rating the arm conditions based on different roles. The scales ranged from 1 to 5. Further information on the Likert scales used can be found in the Appendix section. The results are as follows:

1. **Therapist Real Arm Condition vs Patient Real Arm Condition**
   The following is the comparison of the Real Arm Condition across both roles to identify which role was most suited to this condition based on participant feedback. The feedback was measured with the use of Likert Scales. Data shown are medians of unless otherwise stated. Of the 36 participants recruited to the study, the Real Arm Condition for Therapist elicited 23 participants compared to the patient, whereas four participants saw no improvement and nine participant did not rate the Real Arm Condition for the Therapist above the Real Arm Condition for a Patient. A Wilcoxon signed-rank test determined that there was a statistically significant median increase in performing reaching tasks (-1.0) when used subjects Real Arm Condition for a Patient (4.0) compared to the Real Arm Condition for a Therapist (5.0), $z = 2.475$, $p = .013$.

2. **Therapist Ghost Arm Condition vs Patient Ghost Arm Condition**
   The following is the comparison of the Ghost Arm Condition across both roles to identify which role was most suited to this condition based on participant feedback. The feedback was measured with the use of Likert Scales. Data shown are medians of unless otherwise stated. Of the 36 participants recruited to the study, Ghost Arm Condition for a Patient elicited 16 participants compared to the Ghost Arm Condition for a Therapist, whereas zero participants saw no improvement and twenty participant did not rate the Ghost Arm Condition for the Therapist above

the Ghost Arm Condition for a Patient. A Wilcoxon signed-rank test determined that there was no statistically significant median increase in performing reaching tasks (0.0) when subjects used the Ghost Arm Condition for a Patient (4.0) compared to the Ghost Arm Condition for a Therapist (5.0), $z = 4.000$, $p < .0005$.

3. **Therapist Occlusion Arm Condition vs Patient Occlusion Arm Condition**
The following is the comparison of the Occlusion Arm Condition across both roles to identify which role was most suited to this condition based on participant feedback. The feedback was measured with the use of Likert Scales. Data shown are medians of unless otherwise stated. Of the 36 participants recruited to the study, the Occlusion Arm Condition for a Therapist elicited 16 participants compared to the Occlusion Arm Condition for a Patient, whereas zero participants saw no improvement and twenty participant did not rate the Occlusion Arm Condition for the Therapist above the Occlusion Arm Condition for a Patient. A Wilcoxon signed- rank test determined that there was no statistically significant median increase in performing reaching tasks (0.0) when subjects used the Occlusion Arm Condition for a Patient (4.0) compared to the Occlusion Arm Condition for a Therapist (5.0), $z = 4.000$, $p < .0005$.

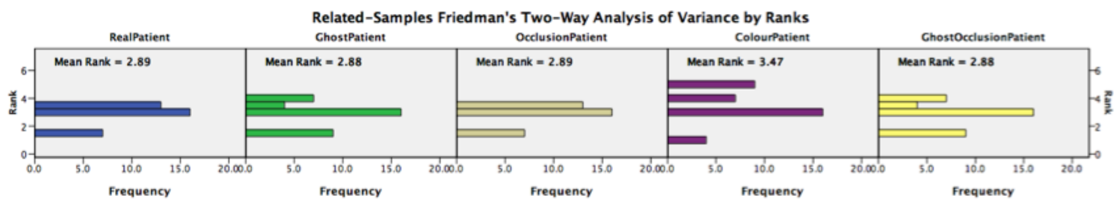
4. **Therapist Colour Arm Condition vs Patient Colour Arm Condition**
The following is the comparison of the Colour Arm Condition across both roles to identify which role was most suited to this condition based on participant feedback. The feedback was measured with the use of Likert Scales. Data shown are medians of unless otherwise stated. Of the 36 participants recruited to the study, the Colour Arm Condition for a Therapist elicited 16 participants compared to the Colour Arm Condition for a Patient, whereas seven participants saw no improvement and thirteen participant did not rate the Colour Arm Condition for the Therapist above the Colour Arm Condition for a Patient. A Wilcoxon signed-rank test determined that there was no statistically significant median increase in performing reaching tasks (0.0) when subjects used the Colour Arm Condition for a Patient (4.0) compared to the Colour Arm Condition for a Therapist (5.0), $z = 1.877$, $p = .061$.

5. **Therapist Ghost Occlusion Arm Condition vs Patient Ghost Occlusion Arm Condition**
The following is the comparison of the Ghost Occlusion Arm Condition across both roles to identify which role was most suited to this condition based on participant feedback. The feedback was measured with the use of Likert Scales. Data shown are medians of unless otherwise stated. Of the 36 participants recruited to the study, the Ghost Occlusion Arm Condition for a Therapist elicited 25 participants compared to the Ghost Occlusion Arm

Condition for a Patient, whereas seven participants saw no improvement and four participant did not rate the Ghost Occlusion Arm Condition for the Therapist above the Ghost Occlusion Arm Condition for a Patient. A Wilcoxon signed-rank test determined that there was no statistically significant median increase in performing reaching tasks (0.0) when subjects used the Ghost Occlusion Arm Condition for a Patient (4.0) compared to the Ghost Occlusion Arm Condition for a Therapist (5.0), z = 3.182, p = 0.001.

6. **Comparison of Therapist Arms**
   After completing the therapist role part of the experiment. Participants were asked to rate the different arm conditions for in terms of how easy it was to lead the AI patient in reaching tasks. The Likert scale ranged from 1 to 5, where 1 = "Very Difficult", and 5 = "Very Easy".

   A Friedman test was run to determine if there were differences in arm conditions ease of use completion during the interaction construct experiment. Arm conditions means were as follows: Real Arm Condition (M = 4.31, SD = 0.86), Ghost Arm Condition (M = 4.31, SD = 0.86), Occlusion Arm Condition (M = 4.36, SD = 0.80), Colour Arm Condition (M = 4.5, SD = 0.81) to Ghost Occlusion Arm Condition (M = 4.36, SD = 0.80). The differences were not statistically significant, 2(4) = 9.420, p = .051.



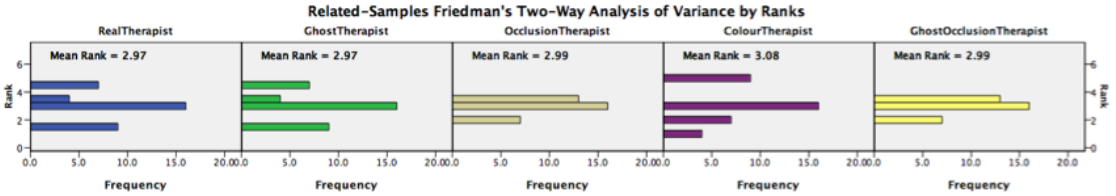
Total N	36
Test Statistic	9.420
Degrees of Freedom	4
Asymptotic Sig. (2-sided test)	.051

1. Multiple comparisons are not performed because the overall test retained the null hypothesis of no differences.

Figure 9.5: Comparison of Therapist Arm Conditions

7. **Comparison of Patient Arms**
   After completing the patient role part of the experiment. Participants were asked to rate the different arm conditions for in terms of how easy it was to follow the AI therapist in reaching tasks. The Likert scale ranged from 1 to 5, where 1 = "Very Difficult", and 5 = "Very Easy".

   A Friedman test was run to determine if there were differences in arm conditions ease of use completion during the interaction construct experiment. Arm conditions means were as follows: Real Arm Condition (M = 3.92, SD = 0.55), Ghost Arm Condition (M = 3.86, SD = 0.59), Occlusion Arm Condition (M = 3.92, SD = 0.55), Colour Arm Condition (M = 4.25, SD = 0.44) to Ghost Occlusion Arm Condition (M = 3.86, SD = 0.59). The differences were not statistically significant, 2(4) = .300, p = .990.



Total N	36
Test Statistic	.300
Degrees of Freedom	4
Asymptotic Sig. (2-sided test)	.990

1. Multiple comparisons are not performed because the overall test retained the null hypothesis of no differences.

Figure 9.6: Comparison of Patient Arm Conditions

8. **Picking Best Patient Arm Condition**
   Of the 36 participants recruited to the study, 10 picked Ghost Occlusion Arm Condition, 9 picked Colour Arm Condition, 9 picked Real Arm Condition, 6 picked Ghost Arm Condition, and 2 picked Occlusion Condition. A chi-square goodness-of-fit test was conducted to determine whether an equal number of participants from each of the five arm conditions were picked in the study. The minimum expected frequency was 7.2. The chi- square goodness-of-fit test indicated that the five arm conditions were equally represented by the participants recruited to the study (2(4) = 5.944, p = .203).

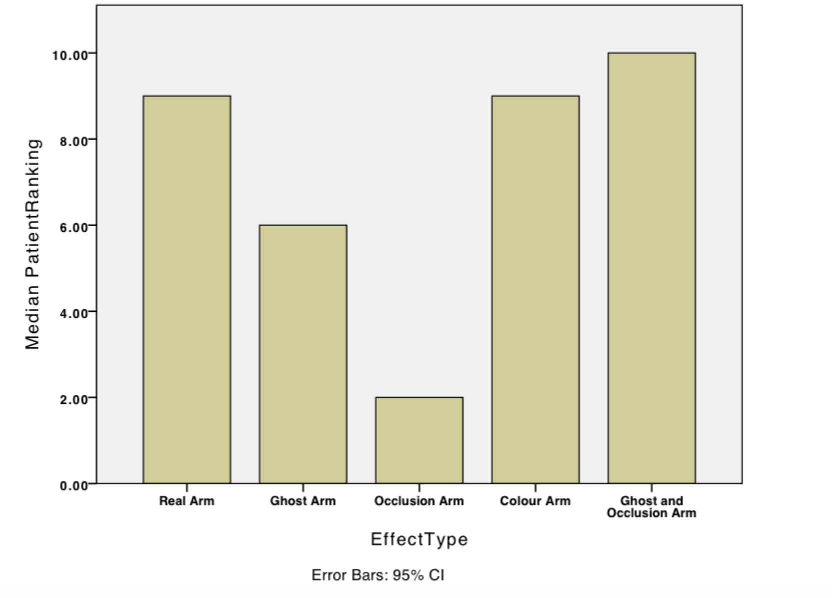


Figure 9.7: Ranking averages of Patient Arm Conditions

9. **Picking Best Therapist Arm Condition**
   Of the 36 participants recruited to the study, 16 picked Ghost Occlusion Arm Condition, 7 picked Colour Arm Condition, 4 picked Real Arm Condition, 9 picked Ghost Arm Condition, and 0 picked Occlusion Condition. A chi-square goodness-of-fit test was conducted to determine whether an equal number of participants from each of the five arm conditions were picked in the study. The minimum expected frequency was 7.2. The chi-square goodness-of-fit test indicated that the five arm conditions were not equally represented by the participants recruited to the study (2(4) = 19.833, p = .001).

10. **Comparing Therapist to Patient Arm Condition Ranking**
    A chi-square test for association was conducted between Therapist and Patient Arm conditions for ease of use in reaching tasks during the interaction construct experiment. Four of the expected cell frequencies were greater than five in Patient and five in Therapist. There was no statistically significant association between Therapist 2(3) = .600, p = .896 and Patient 2(4) = .000, p = 1.0 arm conditions for ease of use in reaching tasks.

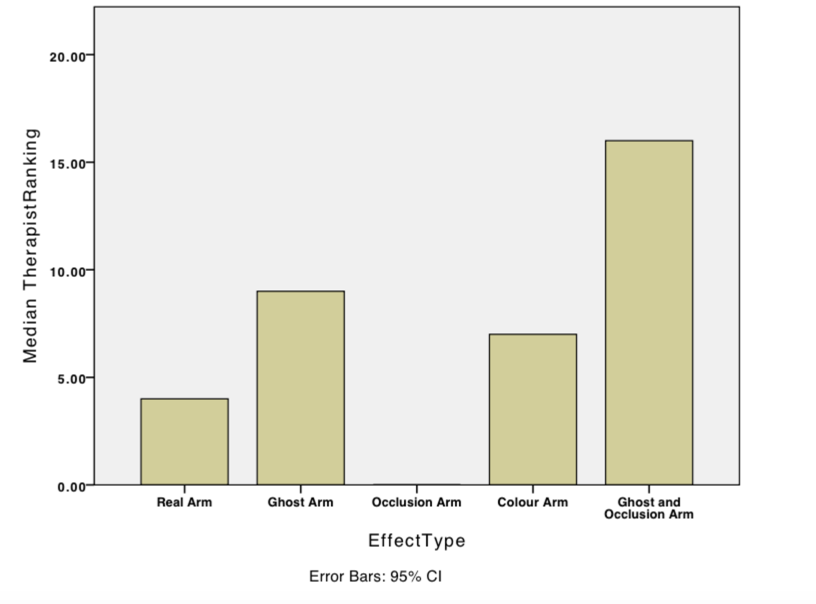


Figure 9.8: Ranking averages of Therapist Arm Conditions

9.4.3. Qualitative Feedback

Participants Feedback on Conditions

Patient Feedback		
	Feedback	**Comments**
Observations	The patient adherence was easier to use than the therapist. This could be due to the effects of action observation treatment. Participants focused more on catching butterflies than they did the effects on the arm; Participants found the AI controlled arm to be creepy with it moving by itself as they controlled the other arm. There was comments about arm that is following being real and the other Ghost Occlusion.	"So easy as you just follow the hand" "Arm following should always be solid"

Table 9.4: Patient Feedback

Therapist Feedback		
	Feedback	Comments
Observations	The patients arm always felt in the way of carrying out the reaching tasks. Other comments was that the local users arm should always be a fixed type (real) and the other arm different (Ghost Occlusion). More comments on effects change compared to patient. This could be due to the other arm getting in the way of catching the butterflies so requires more concentration from the participants. Some participants did get stuck on butterflies in the centre of the screen.	"patient arm is blocking my view of what I was trying to do" "two arms need to be different" "local person always solid and remote transparent"

Table 9.5: Therapist Feedback

Ideal System

Reported in the previous experiments, see Chapters 7 and 8, was the ranking of tracking and display devices. Participants were were asked in the interview to reflect upon their choices and create their ideal system by combining one tracking device and one display device they had tested together. There was possibility of 20 combinations (5 tracking devices and 4 display devices). The following statistics is the combinations chosen by participants without knowledge of what any other participant suggested as their ideal system from tracking and display devices:

Chosen Systems		
Combinations		Number of Participants
Large Display	Kinect V1 or V2	1
	Kinect V1	1
	Kinect V2	1
VisionSpace 2D	Mouse	1
	Kinect V2	4
	Flock of Birds	1
VisionSpace 3D	Mouse	1
	Kinect V1 or V2	2
	Kinect V2	2
	Flock of Birds	1
Oculus	Mouse	1
	Kinect V1 or V2	3
	Kinect V2	11
	Flock of Birds	6

Figure 9.9: Ideal System

From the above, we can see that Kinect V2 added with Kinect V1 or Kinect V2 formed 24 of the 36 participants choice for tracking with Oculus being 19 of the 36 for display. Almost half of the participants(14 of 36) chose the Oculus and Kinect v2 as their most ideal system: combining Kinect V2 with Kinect V1 or V2 group. This is 1.3 times greater than the closet combination of Oculus and Flock of Birds(6 of 36). The results of the interview are consistent with previous results on ranking choices.

9.4.4. Threats to Validity

Four participant were missing a time score for Patient and one participant for Therapist. These participant had their results removed for the calculations on completion time.

9.5. Discussion of Results

9.5.1. Statistical Summary

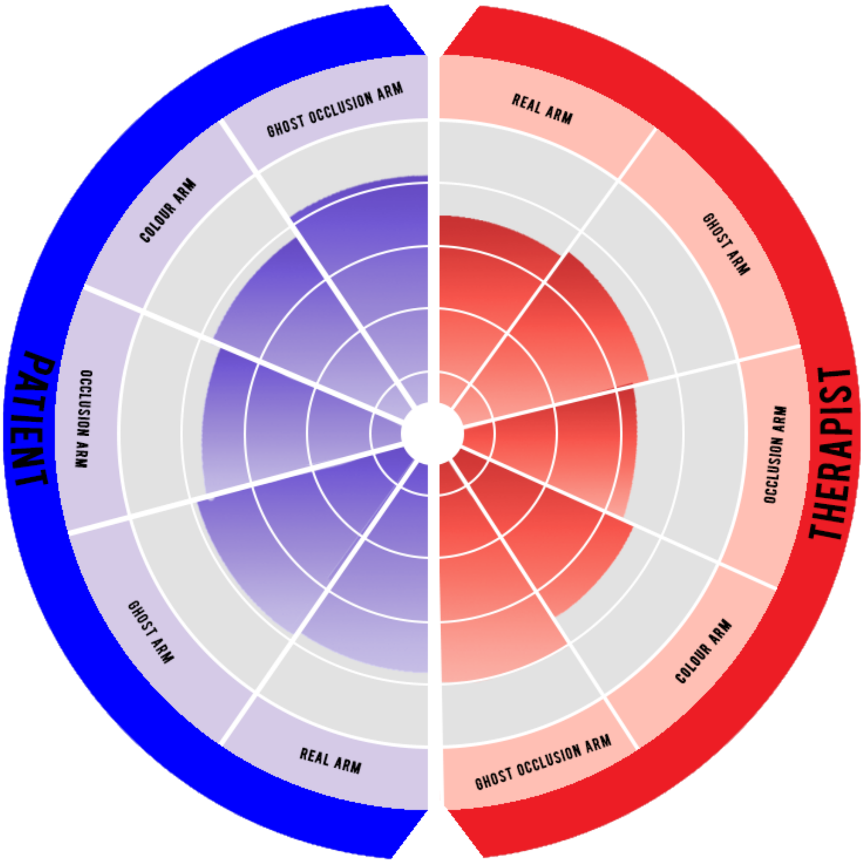
From the statistics conducted from the adherence experiment, we can show that the Patient Condition had the fastest completion time compared to the Therapist Condition. Amongst the Arm conditions, there were significant results found for Real and Ghost Occlusion with White Colour.

When comparing the Patient Arm conditions against each other, we found no significant differences. In the picking of the best arm condition for patient, it was found that Ghost Occlusion, Colour Arm and Real Arm were all very similar. Averaging 9-10 participants each. In the picking of the best arm condition for Therapist, it was found that the Ghost Occlusion Arm was the most favoured with 16 participants choosing it as the most preferred method.

When comparing Patient arm ranking to Therapist arm ranking, no significant results were found.

By combining the above results in statistics and the results from the qualitative feedback, we determine that the Patient Arm condition is best suited for collaboration with a Therapist is the Real Arm, while the best Therapist Arm condition is the Ghost Occlusion Arm.

The following table shows the mean of Likert results in a radar pie table for the different arm effects used in patient and therapist interaction construct condition.



Interaction Construct Likert Results Mean					
	Real Arm	Ghost Arm	Occulsion Arm	Colour Arm	Ghost Occlusion Arm
Patient	3.83	3.97	3.72	3.83	4.16
Therapist	3.44	3.69	3.38	3.63	4.00

Figure 9.10: Likert Results Mean for Interaction Construct

9.5.2. Qualitative Summary

Based on feedback from the participants we found that the Patient Adherence is easier than the Therapist Adherence in performing reaching tasks. This can be attributed to two factors: The first being action observation treatment. It is easier to follow than to lead as you have the animation or action that you need to follow. So in essence you have a training simulation. The second factor is that there is no conflict in your movements as you are being guided. Compared to the Therapist who has to lead the reaching tasks with the other patient's arm sometimes getting in the way.

It was also found that the game elements were not as effective in the adherence experiment compared to the tracking and display experiment. This could be due to the depth information provided by the Oculus, Kinect V2 ease of use and the addition of another Arm controlled by an AI in the game.

Differences in the visual representations of the arms between collaborators are needed. It has been suggested by some participants that the arm combination be either the Therapist always Ghost Occlusion and patient Real or the local user always being Real with the remote user always being Ghost Occlusion. When taking the statistics into account, we can see that the preferred method for Therapist is Ghost Occlusion and while the Patient is Real, Ghost Occlusion or Colour. The selected choice for the Patient arm are all conditions which should work well with the Therapist Ghost Occlusion but further investigation is needed with groups of two users collaborating together with varying arm combinations. What does stand out though, is the need for visual differences to avoid confusion during collaboration.

Participants were also asked which tracking and display devices they would prefer for such a collaboration system. Based on ranking and combinations, again there is strong evidence to suggest Kinect V2 with Oculus to be the most suitable. There were also suggestions for AR to be implemented with Webcams attached to the Oculus. This would allow the user to see their own body (as a video image) while at the same time having the collaborators body overlaid. This falls in line with the long term research goal of this project. But still participants the found the current system impressive and "cool" to use.

10. Experiment 4: Serious Game Evaluation

In this chapter, the researcher presents the results from the adherence experiments. These results include: observations, interviews, questionnaires and statistical information relevant to the experiment.

10.1. Evaluation Goals

The primary goal for the experiment was to compare different game components to see how they could be used for stroke rehabilitation. The game components are broken into different categories: depth perception, game mechanics and performance.

The hypothesizes is: *Serious games can be used as a tool for the creation of rehabilitation exercise.*

With the null hypothesis of: *Serious games cannot be used as a tool for the creation of rehabilitation exercise.*

10.2. Equipment

10.2.1. Game Component Information

The game components are outlined in Chapter 5.4 but a summary is provided below:

1. **Depth Perception -** This includes game components that help the participant navigate the 3D virtual world in the Butterfly Game. These

components are as follows: Reach Gauge, Minimap, Line Render, 3D Arm Shadow Cursor, and Collected Butterfly Particles.

2. **Game Mechanics -** This includes game components that have specific roles within the Butterfly Game and contribute to the game as a whole. These components are as follows: Butterfly Model, Arm Model, Butterfly Shadow Cursor, Spawn Particles, Score Particles, Spawn Message, Collected Message, Sound Effects, and Turtle Feedback.

3. **Performance -** This includes game components that provide feedback on performance during and after the game. These components are as follows: Reach Target Number, Clock, and Results Table.

10.3. Experiment Design

The original participants who took part in the other experiments also participated in this serious games experiment. They provided feedback on the game and its components. In the interview section they were also asked what was the best experience for them across the experiments with the main differences being in performance feedback, depth perception and gameplay.

The following subsections were also based on those outlined in Chapter 6.3.1- 6.3.4:

1. **Participants -** The same Thirty-Six(36) participants recruited for the tracking experiment were recruited again for the serious game experiment.

2. **Measurements -** The measurements were the same as outlined in Chapter 6.2. The only difference being the independent variable being Arm Conditions over Tracking Devices.

3. **Material and Procedures -** The same material and procedures were used as outlined in Chapter 6.3.3.

4. **Experimental process-** The same process for the experiment was used as outlined in Chapter 6.3.4. The only difference being that the independent variables were different game components rather than Tracking Devices.

Pilot Testing
Pilot testing revealed the difficulties in judging depth in a 3D environment from using a 2D display in the real world. To work around this depth perception problem, a number of components were created to further aid the users in navigating the game environment:

1. 3D Arm.
2. Reach Gauge.
3. Shadow Cursor for Butterfly and Arm Models.
4. Line Render.
5. Mini Map9.
6. Environment props in the Game.

10.4. Results and Analysis

10.4.1. Results

From analyzing the results gained from the serious games experiment, we can ascertain the contribution to performance of each component involved in the Butterfly Game. It was shown that, Minimap provided the best depth perception when using a 2D display In this regard the independent variables 'Results Table' provided the best performance feedback and the 'Arm Model' the best game mechanism.

10.4.2. Statistical Results from Experiment

This section will show the statistical analysis gather from the serious game experiment. In the serious games experiment, 36 participants completed tracking, display and adherence experiments. No participants were removed from the data collection or analysis.

Likert Results

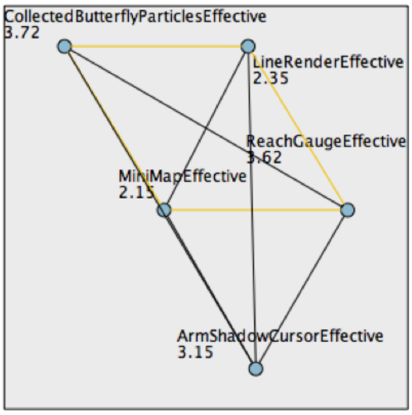
The Likert results in this section were rating the different game components based on several scales. The scales ranged from 1 to 5. Further information on the Likert scales used can be found in the Appendix section. The scales are as follows:

- **Effectiveness - This refers to how well the game component performed in its task as rated by participants.**

- **Enhanced -This refers to how well the game component added to the virtual world as a whole as rated by participants.**

1. **Comparing Depth Perception Components Effectiveness**
   After completing the experiment participants rated the depth perception game components on whether they helped with depth perception/navigation in the Butterfly Game. The Likert scale ranged from 1 to 5, where 1 = "Very Effective", and 5 = "Not Very Effective".

Pairwise Comparisons



Each node shows the sample average rank.

Sample1-Sample2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj.Sig.
MiniMapEffective-LineRenderEffective	-.194	.373	-.522	.602	1.000
MiniMapEffective-ArmShadowCursorEffective	-1.000	.373	-2.683	.007	.073
MiniMapEffective-ReachGaugeEffective	1.472	.373	3.950	.000	.001
MiniMapEffective-CollectedButterflyParticles Effective	-1.569	.373	-4.211	.000	.000
LineRenderEffective-ArmShadowCursorEffective	-.806	.373	-2.162	.031	.307
LineRenderEffective-ReachGaugeEffective	1.278	.373	3.429	.001	.006
LineRenderEffective-CollectedButterflyParticles Effective	-1.375	.373	-3.690	.000	.002
ArmShadowCursorEffective-ReachGaugeEffective	.472	.373	1.267	.205	1.000
ArmShadowCursorEffective-CollectedButterflyParticles Effective	-.569	.373	-1.528	.127	1.000
ReachGaugeEffective-CollectedButterflyParticles Effective	-.097	.373	-.261	.794	1.000

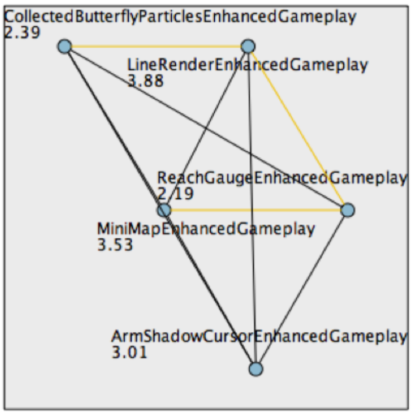
Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is .01.

Figure 10.1: Results for Effectiveness of Depth Perception game components

A Friedman test was run to determine if there were differences in depth perception components in their effectiveness for depth perception during the serious games experiment. Pairwise comparisons were performed (SPSS, 2012) with a Bonferroni correction for multiple comparisons. Statistical significance was accepted at the $p < .01$ level. Depth perception components was statistically significantly different amongst the tested components, 2(4) = 38.092, $p < .0005$. Post hoc analysis revealed statistically significant difference in depth components from Minimap (M = 1.92, SD = 1.08) to Reach Gauge (M = 2.94, SD = 1.19) ($p = .001$), Minimap to Collected Butterfly Particles (M = 2.89, SD = 0.71) ($p < .0005$), Line Render (M = 1.92, SD = 0.81) to Reach Gauge ($p = .006$) and Liner Render to Collected Butterfly Particles ($p = .002$). There were no other depth components comparisons which showed significant results.

2. **Comparing Depth Perception Components Enhancing Gameplay**
   After completing the experiment participants rated the depth perception components on whether they enhanced the gameplay of the Butterfly Game. The Likert scale ranged from 1 to 5, where 1 = "Strongly Disagree", and 5 = "Strongly Agree".

Pairwise Comparisons



Each node shows the sample average rank.

Sample1-Sample2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj.Sig.
ReachGaugeEnhancedGameplay-CollectedButterflyParticlesEnhancedGameplay	-.194	.373	-.522	.602	1.000
ReachGaugeEnhancedGameplay-ArmShadowCursorEnhancedGameplay	-.819	.373	-2.199	.028	.279
ReachGaugeEnhancedGameplay-MiniMapEnhancedGameplay	-1.333	.373	-3.578	.000	.003
ReachGaugeEnhancedGameplay-LineRenderEnhancedGameplay	-1.681	.373	-4.509	.000	.000
CollectedButterflyParticlesEnhancedGameplay-ArmShadowCursorEnhancedGameplay	.625	.373	1.677	.094	.935
CollectedButterflyParticlesEnhancedGameplay-MiniMapEnhancedGameplay	1.139	.373	3.056	.002	.022
CollectedButterflyParticlesEnhancedGameplay-LineRenderEnhancedGameplay	1.486	.373	3.988	.000	.001
ArmShadowCursorEnhancedGameplay-MiniMapEnhancedGameplay	.514	.373	1.379	.168	1.000
ArmShadowCursorEnhancedGameplay-LineRenderEnhancedGameplay	.861	.373	2.311	.021	.209
MiniMapEnhancedGameplay-LineRenderEnhancedGameplay	-.347	.373	-.932	.351	1.000

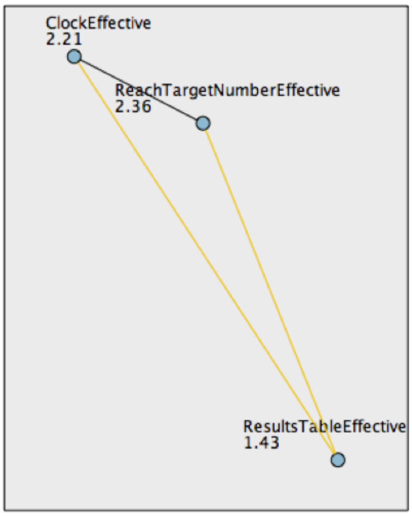
Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is .01.

Figure 10.2: Results for game Enhancement for Depth Perception game components

A Friedman test was run to determine if there were differences in depth perception components in enhancing gameplay during the serious games experiment. Pairwise comparisons were performed (SPSS, 2012) with a Bonferroni correction for multiple comparisons. Statistical significance was accepted at the $p < 0.1$ level. Depth perception components were statistically significantly different amongst the tested components, $2(4) = 40.354$, $p < .0005$. Post hoc analysis revealed statistically significant differences in depth components from Reach Gauge ($M = 2.9444$, $SD = 1.19$) to Minimap ($M = 3.8889$, $SD = 1.19$) ($p = .003$), Reach Gauge to Line Render ($M = 4.1944$, $SD = 0.79$) ($p < .0005$) and Collected Butterflies Particles ($M = 3.1667$, $SD = 0.74$) to Liner Render ($p = .001$). There was almost a significant difference in Collected Butterflies Particles to Minimap ($p = .022$) but no other depth components comparisons which showed significant results.

3. <u>**Comparing Performance Components Effectiveness**</u>
   After completing the experiment participants rated the performance game components on whether they helped with providing feedback on their performance during and on completing the Butterfly Game. The Likert scale ranged from 1 to 5, where 1 = "Very Effective", and 5 = "Not Very Effective".

Pairwise Comparisons



Each node shows the sample average rank.

Sample1-Sample2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj.Sig.
ResultsTableEffective-ClockEffective	.778	.236	3.300	.001	.003
ResultsTableEffective-ReachTargetNumberEffective	.931	.236	3.948	.000	.000
ClockEffective-ReachTargetNumberEffective	.153	.236	.648	.517	1.000

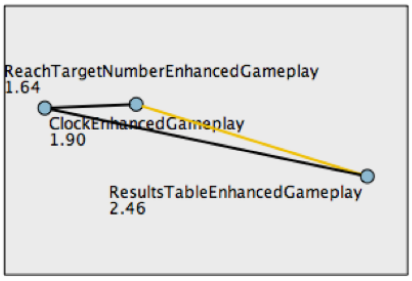
Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is .02.

Figure 10.3: Results for Effectiveness of Performance game components

A Friedman test was run to determine if there were differences in performance components in their effectiveness for showing user performance during the serious games experiment. Pairwise comparisons were performed (SPSS, 2012) with a Bonferroni correction for multiple comparisons. Statistical significance was accepted at the $p < .016667$ level. Performance components was statistically significantly different amongst the tested components, 2(2) = 30.376, $p < .0005$. Post hoc analysis revealed statistically significant differences in performance components from Results Table (M = 1.43, SD = 0.61) to Clock (M = 2.21, SD = 1.28) (p = .003) and Results Table to Reach Target Number (M = 2.36, SD = 1.10) ($p < .0005$). There was no other performance components comparisons which showed significant results.

4. **<u>Comparing Performance Components Enhancing Gameplay</u>**
   After completing the experiment participants rated the performance components on whether they enhanced the gameplay of the Butterfly Game. The Likert scale ranged from 1 to 5, where 1 = "Strongly Disagree", and 5 = "Strongly Agree".

Pairwise Comparisons



Each node shows the sample average rank.

Sample1-Sample2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj.Sig.
ReachTargetNumberEnhanced Gameplay-ClockEnhancedGameplay	-.264	.236	-1.120	.263	.789
ReachTargetNumberEnhanced Gameplay-ResultsTableEnhanced Gameplay	-.819	.236	-3.477	.001	.002
ClockEnhancedGameplay-ResultsTableEnhanced Gameplay	-.556	.236	-2.357	.018	.055

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is .02.

Figure 10.4: Results for game Enhancement for Performance game components

A Friedman test was run to determine if there were differences in performance components in enhancing gameplay during the serious games experiment. Pairwise comparisons were performed (SPSS, 2012) with a Bonferroni correction for multiple comparisons. Statistical significance was accepted at the $p < .016667$ level. Performance components was statistically significantly different amongst the tested components, $2(2) = 20.156$, $p < .0005$. Post hoc analysis revealed statistically significant differences in performance components from Results Table ($M = 2.46$, $SD = 0.69$) to Reach Target Number ($M = 1.64$, $SD = 1.02$) ($p = .002$). There was almost a significant results with Clock ($M = 1.90$, $SD = 1.12$) to Results Table ($p = .055$) no other performance components comparisons which showed significant results.

5. **Comparing Game Mechanics Components Effectiveness**

   After completing the experiment participants rated the game mechanic game components on whether their role was useful to have in the Butterfly Game. The Likert scale ranged from 1 to 5, where 1 = "Very Effective", and 5 = "Not Very Effective".

   A Friedman test was run to determine if there were differences in game mechanic components in their effectiveness during the serious games experiment. Pairwise comparisons were performed (SPSS, 2012) with a Bonferroni correction for multiple comparisons. Statistical significance was accepted at the $p < .0055$ level. Game Mechanic components was statistically significantly different amongst the tested components, $2(8) = 58.725$, $p < .0005$. The following are the results that were significant: Butterfly Model to Turtle Feedback, Sound Feedback to Turtle Feedback, Arm Model to Turtle Feedback and Spawn Message to Turtle Feedback. The only other comparison of note was Score Particles to Turtle Feedback but no other game mechanic components showed significant results.

6. **Comparing Game Mechanics Components Enhancing Gameplay**

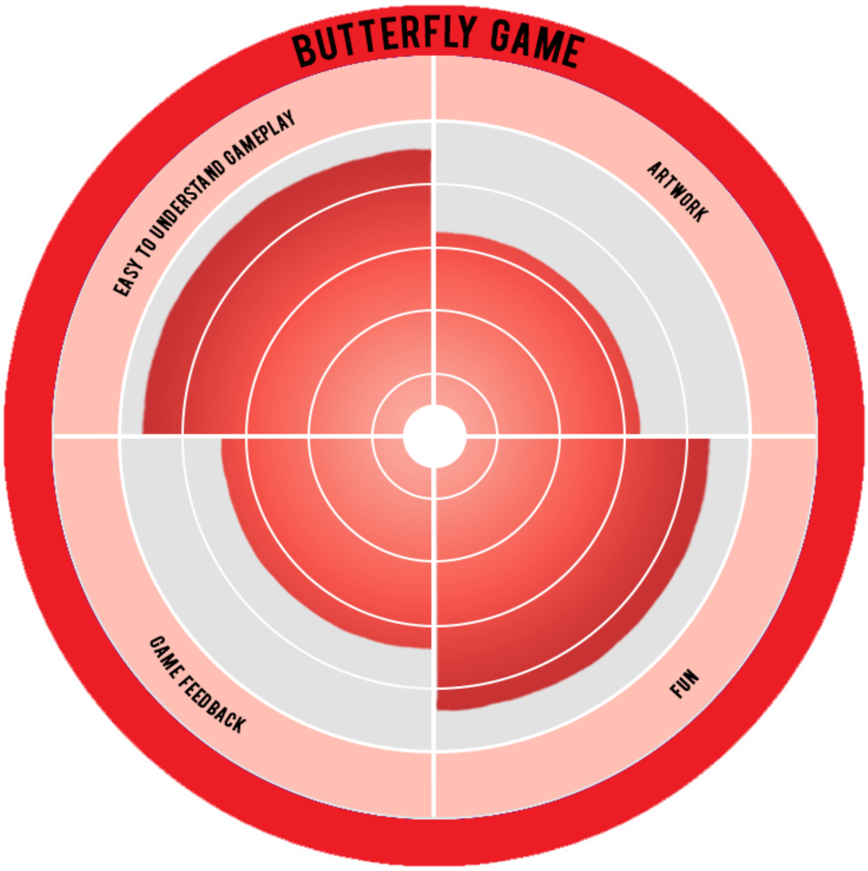
   After completing the experiment participants rated the game mechanic components on whether they enhanced the gameplay of the Butterfly Game. The Likert scale ranged from 1 to 5, where 1 = "Strongly Disagree", and 5 = "Strongly Agree".

   A Friedman test was run to determine if there were differences in game mechanic components in enhancing gameplay during the serious games experiment. Pairwise comparisons were performed (SPSS, 2012) with a Bonferroni correction for multiple comparisons. Statistical significance was accepted at the $p < .0055$ level. Game Mechanic components was statistically significantly different amongst the tested components, $2(8) = 59.598$, $p < .0005$. The following are the results that were significant: Turtle Feedback to Butterfly Model, Turtle Feedback to Arm Model and Turtle Feedback to Sound Effects. There was almost significant results from Spawn Particles to Sound Effects, Collected Message to Sound Effects and Score

Particles to Sound Effects but no other game mechanic components showed significant results.

Radar Pie Charts

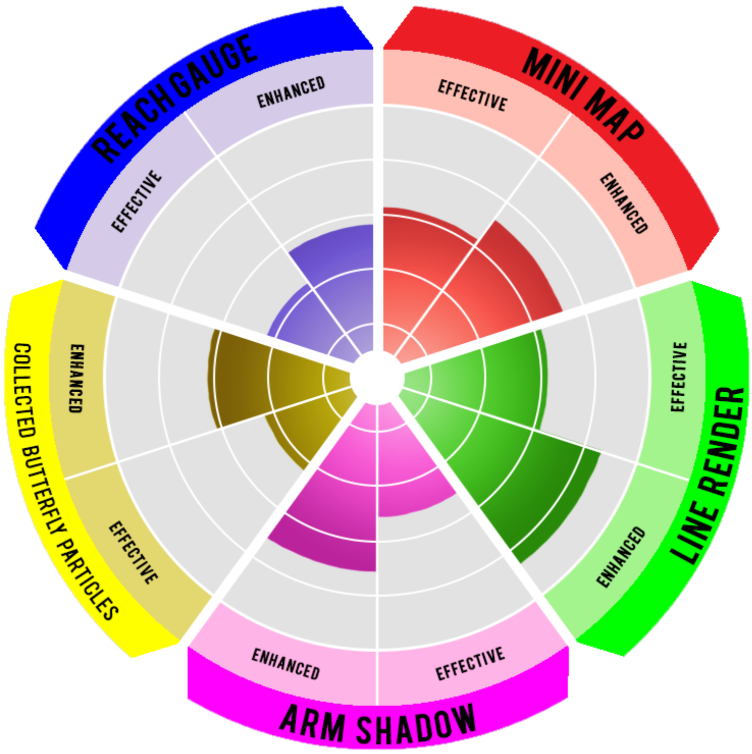
The following table shows the mean of Likert results for Gameplay in a radar pie table.



Game Likert Results Mean				
	Artwork	**Fun**	**Game Feedback**	**Easy To Understand Gameplay**
Butterfly Game	3.20	4.36	3.23	4.66

Figure 10.5: Likert Results Mean for Gameplay

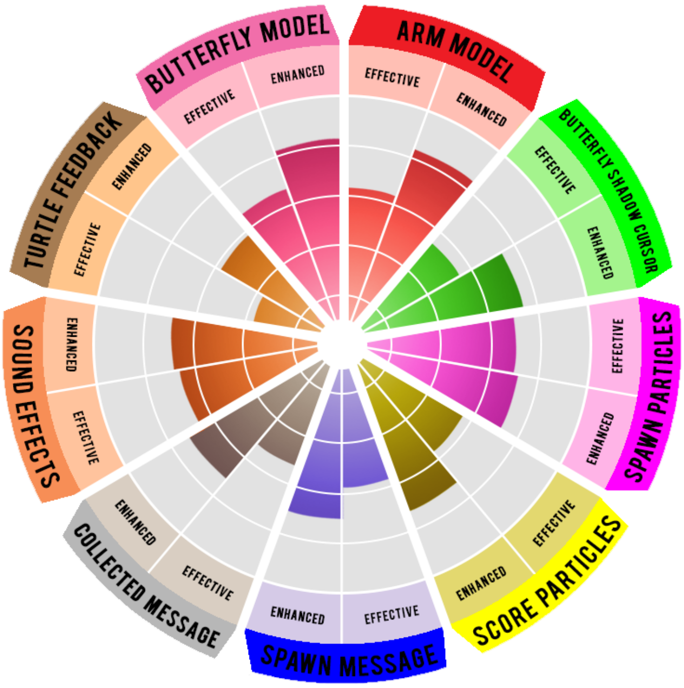
The following table shows the mean of Likert results for Depth perception in a radar pie table.



Depth Perception Likert Results Mean		
	Effective	**Enhanced**
Reach Gauge	2.09	2.94
Mini Map	3.09	3.88
Line Render	3.09	4.19
Arm Shadow	2.52	3.63
Collected Butterfly Particles	2.14	3.16

Figure 10.6: Likert Results Mean for Depth perception game components

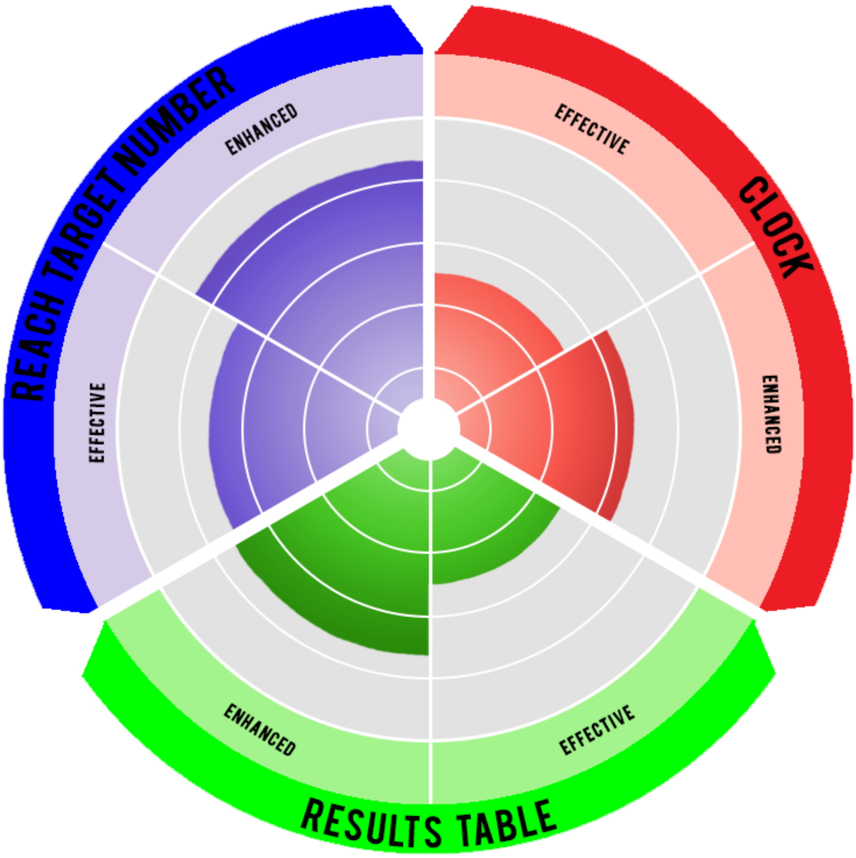
The following table shows the mean of Likert results for Game Mechanics in a radar pie table.



Game Mechanics Likert Results Mean		
	Effective	**Enhanced**
Butterfly Model	3.18	4.13
Arm Model	3.09	4.16
Butterfly Shadow Cursor	2.68	3.75
Spawn Particles	2.55	3.52
Score Particles	2.73	3.61
Spawn Message	2.73	3.44
Collected Message	2.40	3.44
Sound Effects	3.30	4.41
Turtle Feedback	1.91	2.91

Figure 10.7: Likert Results Mean for Game Mechanics game components

The following table shows the mean of Likert results for Performance in a radar pie table.



Performance Likert Results Mean		
	Effective	**Enhanced**
Clock	4.41	3.36
Results Table	2.55	3.66
Reach Target Number	3.49	4.38

Figure 10.8: Likert Results Mean for Performance game components

10.4.3. Qualitative Feedback

The following information was gained from the questionnaires collected from the participants. The data has been compiled and compressed into the following tables for easy digestion.

Best Experience
Participants were asked in the post hoc interview what was their best experience

across all the experiments they have done. From their feedback, three main points came across:

1. Oculus: Participants gave an overwhelming response to the Oculus. Comments of it being impressive and cool when combined with the serious game. They felt immersed, could reach out and touch the butterflies as if they were real without the need for additional feedback mechanics as is needed with 2D displays.
2. Natural Gestures: The 3D arm felt like their real arm in the game when using the kinect. This felt more natural and increased immersion levels.
3. Various Equipment: Trying out different forms of technology was rated high amongst participants. They also suggested the concept of tactile feedback via holding something. It appears that some users don't like holding anything while others prefer holding something for tactile feedback(like a Wii remote to act as a net for catching butterflies).

Overall the participants had a lot of fun in the experiments and without being asked, volunteered to be part of further research projects and experiments. Participants commented on how it was the longest study they have ever been involved in but also the most enjoyable(Best experience). They would then tell other people about the research project by their own free will, which resulted in a constant supply of participants for testing by those eager to be involved in the study. This type of feedback shows the motivation, engagement in the serious game as well as the value in undertaking such a research project.

Observations

1. Didn't Notice: Most of the participants didn't notice all of the game components. This could be looked upon in a positive light. If the participants got faster and not slower, it means they were unconsciously using the components and the components themselves were not a hindrance during gameplay. This can also be looked on with the user expecting it to be there and noticing it when it is not. Similar to the way bass and drums are in a song, you might not notice when they are blended into the rest of the music but you do notice when they are missing.

One comment from a participant was on how driving in Sydney requires great levels of observation and how Christchurch drivers seem to not be as aware of their surrounding due to how traffic levels differ. Another comment was whether the game was suitable for colour blind people and told how the participant had to guide their friend from the ground level with a laser point in indoor rock climbing, due to all the hands and footholds being colour code on how to progress upwards.

It was observed that users performed more natural and were at ease in reaching tasks when using 3D displays. The reason could be due to 3D offering natural depth perception compared to 2D which needs additional feedback mechanics which in turn requires more observation and multitasking skills. In 3D the butterfly is the depth information whereas 2D does not provide that information and needs to be supplied through other means. This can be compared to zooming in on a photo on a touchscreen device with your fingers and using the old traditional method of magnifying glasses and move tools; Both methods work but one has the information act as the interface while the other needs tools to work with the medium.

Feedback on Serious Game

Butterfly Game			
Feedback		Comments	
Positive	Game was at a very high and professional level; sound was satisfying; graphics were good and the game was user friendly - no learning needed; Game was very natural to use and was fun.	*"t was fun, felt like a very professional game. The sound effects were especially satisfying."* *"I would not have any negative aspects of this game design when considering the purpose of the game. As I feel it's design is very effective."* *"Minimaps weren't as effective with the more 3d options."* *"Children's learning game. Could always release more butterflies and tell use to collect so many of a particular color. Learn counting and colors that way."*	
Negativ	Popup words were annoying; in adherence the two arms block butterfly view; need variations of insects.		
Improveme	Could make learning games and exercise routines;		
Modifications	Make the world more dynamic with constant changes so users login to see what the world is like and not only to play the game; change camera view.		

Table 10.1: Serious Game Feedback

Feedback on Game Components

Performance Feedback	Reach Target Number		
	Positive	Used when stuck or struggling to see how many butterflies were left to catch; didn't notice or use it.	
	Negative	Didn't notice it, focus was elsewhere.	
	Improvements	Have it as a countdown instead of increasing bar; more butterflies to catch; place collected number above butterflies; tweak colours; add insect variation and not just butterflies.	
	Comments		
	"When struggling it allowed to know how far through the game you are." "Most times i was focus only on the task and didn't use the surrounding feedback mechanisms." "I didn't pay any attention on the performance, but just try my best to finish the game as fast as possible." "This would become a useful feature if there were other insects e.g. moths which you don't want to catch. Then it becomes a bit more important."		

Table 10.2: Reach Target Number Feedback

Depth Perception	Minimap		
	Positive	It was helpful and useful in catching tricky butterflies when stuck; It showed the model locations – butterfly and hand position.	
	Negative	Too small and can't multitask between it and the mains screen.	
	Improvements	Make it bigger, more zoomed in; Show when needed.	
	Comments		
	"It was helpful as a guide to the butterflies. Sometimes the big screen can deceive." *"Bit tricky to look at both the map UI and the game."* *"Perhaps zoom in a bit, the map only needs to show the region of the hand and the butterfly."*		

Table 10.3: Minimap Feedback

Depth Perception	Line Render		
	Positive	Was the main tool used, critical, nothing else was needed, provided depth perception and direction, showed movement path needed to be taken.	
	Negative	Noticed in therapist and adherence experiment; alignment issues with other arm blocking butterfly view in adherence experiment so line render became hidden.	
	Improvements	No improvements were suggested.	
	Comments		
	"It was my main source of knowing how far or close I was to the butterfly." "Helped to proved very fast feedback on reach." "Difficult to use when hand was on same y axis location but the wrong z axis location. (Too far/near)" "It would be useful as a toggle option so that it is off by default and can be activated if the butterfly can not be found."		

Table 10.4: Line Render Feedback

Depth Perception	Arm Shadow Cursor		
	Positive	The level of realism, main method used, helpful and increased immersion.	
	Negative	Didn't notice it, wasn't clear that it was a shadow or connected to arm.	
	Improvement s	Clear symbols; show a sun if you have shadow; keep it in the game.	
	Comments		
	"This and the butterfly shadow were my main means of judging distance." "The shadow did enhance the reading of depth in the world. It provided a connection between my fake arm and the 3D world. Helps with immersiveness." "If there is going to be an arm shadow then there should also be a big sun in the frame."		

Table 10.5: Arm Shadow Cursor Feedback(Arm Shadow Cursor Feedback

Depth Perception	Butterfly Collected Particles		
	Positive	Showed butterfly location; made the game more fun; didn't notice it so didn't interfere with the game.	
	Negative	Redundant as butterfly disappearing is enough feedback; didn't notice it.	
	Improvements	Make it more noticeable; make it dynamic, more colours, it works the way it is.	
	Comments		
	"Good indicator but overtly noticeable." "Didn't really notice that they showed depth - although I probably noticed them sub-consciously and benefited from them that way." "Particles appeared as butterfly was collected, so it's kind of moot. The butterfly disappearing is indication enough that the depth is correct." "More dynamic and elaborate effects showing that player catches the butterflies."		

Table 10.6: Butterfly Collected Particles Feedback

Game Mechanics	Butterfly Model		
	Positive	The butterfly animation was good, grabbed the users attention, was tied to other feedbacks, there was variations in the butterflies, it was logical in the environment and game tasks; it was fun and engaging.	
	Negative	Background was a distraction, hard to distinguish butterflies sometimes from background; If I am killing the butterflies that is bad; need more variation.	
	Improvements	Have high contrast between butterflies and background; have the butterflies move around and not in fixed position; have a variety of special effects when they are caught.	
	Comments		
	"The size and colors were good for the game. Friendly target for all ages." "I liked how they flapped their wings." "Sometimes the butterfly blends with the background which makes it hard to see. But the marks helped a lot." "Put different insects not just butterflies, I mean it is just for fun. However that can keep the attention of the user more in the game."		

Table 10.7: Butterfly Model Feedback

<table>
<tr><th rowspan="5">Game Mechanics</th><th colspan="3">Arm Model</th></tr>
<tr><td>Positive</td><td>It brought a level of realism and increased immersion; the Ghost Occlusion effect was good; the connection between users arm and 3D arm was really good with the kinect; the ease of use and efficiency was good.</td><td rowspan="3"></td></tr>
<tr><td>Negative</td><td>Is catching butterflies maybe the arm should hold a net; in adherence the butterflies should be always visible through all the arms with some form of occlusion. The hand didn’t perform a grasping animation when it touched a butterfly.</td></tr>
<tr><td>Improvements</td><td>The arm should not be floating in front but have the shoulder match the location of a real shoulder - camera perspective and arm alignment.</td></tr>
<tr><td colspan="3">Comments
"Can see through arm to get the butterflies."

"The arm represents my real arm in the virtual world and move exactly how I moved. I felt natural and intuitive."

"Sometimes (particularly with the solid models) the hand/arm occluded the butterflies and made it difficult to see where they were."

"Hand grasp.Slightly higher camera angle. looking down a little on the arm. In real life we don’t see our shoulder so this was a little bit of a block for me."</td></tr>
</table>

Table 10.8: Arm Model Feedback

<table>
<tr><td rowspan="6">Game Mechanics</td><td colspan="3">Butterfly Shadow Cursor</td></tr>
<tr><td>Positive</td><td>Helped with depth perception; was helpful; allowed for faster gameplay; could see the effects on the mini map.</td><td rowspan="3"></td></tr>
<tr><td>Negative</td><td>The connection that it was representing the shadow of the butterfly was not clear.</td></tr>
<tr><td>Improvements</td><td>could remove to increase difficulty during level progression; size of the shadow is small linked to z-axis; changing the cursor into a small pillar to stand out above the environment; changing the markers colour depending on distance of hand to butterfly.</td></tr>
<tr><td colspan="3">Comments</td></tr>
<tr><td colspan="3">"The shadows showing the butterfly distance were useful to have, especially for 2d display modes."

"The marker became difficult to see when dealing with scene objects such as the table."

"Perhaps the marker could be a small pillar where you have a solid colour on the ground with a glowy haze coming up. Then scene objects can distort or occlude it."</td></tr>
</table>

Table 10.9: Butterfly Shadow Cursor Feedback

Game Mechanics	Spawn Particles		
	Positive	Good for showing when you successfully caught the previous butterfly; enhance game and shows the location of butterflies.	
	Negative	Attention was elsewhere and not focused on looking for spawn particles.	
	Improvements	Have variation of particles; remove for increased difficulties for level progression.	
	Comments		
	"You now when you catched the butterfly." "The particles is not so obvious to observe because of the colorful background. In contrast, the animation of the butterfly itself cause the attention instead." "Maybe different spark effects just for fun. The user can be motivated to see what will happen once that he/she catches the butterfly."		

Table 10.10: Spawn Particles Feedback

Game Mechanics	Score Particles		
	Positive	Sound effects along with the visual let you know you have hit the target; was fun to see; was a reward and let you know you were successful.	
	Negative	Didn't notice it; can have too much visual feedback if catching butterflies fast; sound effect was more rewarding than particles.	
	Improvements	Variations of spawn particles; voice over telling you your current score.	
	Comments		
	"Liked the effect because I knew to start looking for another butterfly." "Noise and visual knew you had hit the target." "Can have a little to much visual feedback if your moving fast." "More dynamic or elaborate effects that really pops out."		

Table 10.11: Score Particles Feedback

Game Mechanics	Spawn Message		
	Positive	Helped to find butterfly location; was helpful and big to draw attention.	
	Negative	Visual clutter; took some of the challenge away and made it easy – reduced difficulty.	
	Improvements	Have icons or symbols that pulse instead of words.	
	Comments		
	"Draws attention." "With so many colors and butterflies appearing faster , sometimes it may take longer to see them, so the messages are good!" "I actually found them a little cluttering of the UI." "Distracted form the target. Using text to excess in a visual medium." "Don't use words use icons that pulse."		

Table 10.12: Spawn Message Feedback

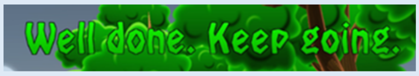
Game Mechanics	Collected Message		
	Positive	Provided motivation; was good for progress feedback; helpful for children.	
	Negative	Visual clutter; sound was better and it's not needed - remove; there was overlapping of words if collected butterflies fast which made it confusing.	
	Improvements	Have variations; change the location the words appear on the screen to an area that won't block main view port; only use if user has not caught a butterfly in a long time; remove it.	
	Comments		
	"It was great to have positive feedback and will be great for children." "Created a bit too much clutter at times." "Don't show it unless the user hasn't got a butterfly for a long time - I don't need encouragement if I can hit each butterfly easily and quickly."		

Table 10.13: Collected Message Feedback

Game Mechanics	Sound Effects
Positive	it let the user know when they were successful in catching a butterfly; provided motivation, non-intrusive, not annoying, helpful and added excitement for when you hear the noise you knew you caught the butterfly.
Negative	Sound overlapped if caught butterflies too fast.
Improvements	Add sound effect for spawning of butterflies; have variations in sound effects; nothing needs to be improved.
Comments	"The sounds were a quick non-intrusive way of informing me what was going on. That is everything I need." "I mostly get exited from sound because it tell me I caught the butterfly." "Can have a lot of sounds overlapping if you go fast." "Give a sound effect for butterfly spawn area, could work improving hearing."

Table 10.14: Sound Effects Feedback

Game Mechanics	Turtle Feedback		
	Positive	Enhanced the game by adding to the visual interest and atmosphere of the game.	
	Negative	Too small and didn't notice him; didn't connect turtle to users actions - purpose of turtle unclear.	
	Improvements	Make the turtle bigger; have the turtle as an AI helper in catching butterflies or pointing them out; have the turtle's feedback more obvious and exaggerated.	
	Comments		
	"Contributed to the overall light-hearted atmosphere." "The turtle was small and off to the right so i didn't make a connection with progress to the turtle character." "An interesting idea could be to get him to chase and eat the butterfly if the player is too slow."		

Table 10.15: Turtle Feedback

Performance Feedback	Reach Target Number		
	Positive	Used when stuck or struggling to see how many butterflies were left to catch; didn't notice or use it.	
	Negative	Didn't notice it, focus was elsewhere.	
	Improvements	Have it as a countdown instead of increasing bar; more butterflies to catch; place collected number above butterflies; tweak colours; add insect variation and not just butterflies.	
	Comments		
	"When struggling it allowed to know how far through the game you are." "Most times i was focus only on the task and didn't use the surrounding feedback mechanisms." "I didn't pay any attention on the performance, but just try my best to finish the game as fast as possible." "This would become a useful feature if there were other insects e.g. moths which you don't want to catch. Then it becomes a bit more important."		

Table 10.16: Reach Target Number Feedback

Performance Feedback	Clock		
	Positive	Helps to track progress; adds a competitive element; you can set a goal; shows your performance between games; provides motivation and is placed well on the screen.	
	Negative	Not the main feature; the format of the clock is not in hours minutes and seconds; no attention is given to it.	
	Improvements	Sound effects for when you pass certain times; size of the clock; have it counting down in a fixed time per game instead of counting how long it takes to complete the game.	
	Comments		
	"I liked to be able to gauge my speed and performance." "Didn't notice the clock i only check times at the end on the main score panel." "Some alarm sound at some point may be? e.g. beep every 1 minute so the player can know the time."		

Table 10.17: Clock Feedback

Performance Feedback	Results Table		
	Positive	Shows your performance in the game; provides motivation as you can see how your improving	
	Negative	The butterflies are always fixed in their number; not sure what gold is used for - irrelevant; its missing results on time butterflies were collected at.	
	Improvement s	Have a purpose for the gold; graph of performance during the game; have the stars in parts and not whole numbers - half a star compared to one star.	
	Comments		
	"I could read my overall performance stats and this was very motivating for me on to do better on the next task." "Gold seem irrelevant." "As the goal of the round was to catch 10 butterflies there is no need to mention that I've caught 10 butterflies at the end." "Not always put full stars. Or... at least parts of stars / percentages. Example, $4.00 becomes $3.99"		

Table 10.18: Results Table Feedback

10.4.4. Threats to Validity

The following is not so much threats to validity as it is highlighting the nature of the results gathered for Game Mechanic Components. Unlike Performance and Depth Perception Components which can be compared against each other in fulfilling similar roles, Game Mechanic Components fulfill different roles to one another. So the results for this section are based on their contribution to the game as a whole. We can say that the usefulness of their presence or absence is based on participants feedback. The rating of their usefulness can also be looked upon as the emotional connection of participants with these components. For example, we have the butterfly model which represents a reach target location; we have a turtle model that gets happy when we collect butterflies and rolls on the ground when we win the game.

10.5. Discussion of Results

10.5.1. Statistical Results Summary

From statistics conducted from the serious games experiment, we can show that Mini Map and Line Render for Depth perception provide significant improvements for *Effectiveness* and *Enhancing Gameplay* as measured by a Likert scale. When combining these statistics with the results from qualitative feedback, we can say these two methods provide beneficial information on depth perception.

For performance components, we can show that the Results Table provided significant results for *Effectiveness* and *Enhancing Gameplay* likert scale. When combining these statistics with the results from the qualitative feedback, we can say the Results Table is beneficial in providing performance feedback.

In Game Mechanic Components, Turtle showed significant results against other components in *Effectiveness* and *Enhancing Gameplay* likert scale. When combining these statistics with the results from the qualitative feedback, we can say that the Turtle was the least noticed and used part of the game.

10.5.2. Qualitative Summary

Based on feedback from participants, it was found that a lot of the game components went unnoticed in varying amounts. But valuable information was still able to be gleaned. The Reach Gauge while only used as a fallback was really helpful when using the Myo Armband for feedback when gestures were recognised and not used in any other condition from other experiments.

Depth components formed the basis of varying techniques that were used by participants. From these techniques came several different groups within the participants that would focus solely on using those components for depth and not the others. The groups are: Minimap, Line Render and Shadow Cursors. The Mini Map was used in a reverse way than intended in 2D displays: participants would focus on the Minimap to get the location of their 3D hand above the butterfly model in X-axis and Z-axis, then they would look to the main screen to adjust the 3D hands height in Y-axis. The other Depth Perception components were used as intended.

In 3D displays, the depth information was provided as a by product of the technology and Depth Perception components were not used or needed. The only exception, being the use of the line render during the Adherence experiment due to the other arm getting in the way. Interestingly, no participants looked to the mini map when the AI controlled arm blocked the butterfly model and sometimes the line render component: the researcher would have to point out the location of the butterfly Model; This was usually butterfly models spawning in the center of the screen.

The results Table was the most favoured performance feedback with participants focusing on the time it had taken them to complete the game. Time was the main motivation for the participants. They focused on getting faster and faster which brought a competitive element to the game.

With the Game Mechanic Components, Sound feedback on catching butterflies was deemed the most helpful and provided a huge motivation for participants as they focused on trying to get the sound to play. The only drawback was that popup words/messages and sound effects could stack on top of each other if butterflies are collected fast. Spacing and controlling of effects is needed. It was also found out that popup words/messages could create visual clutter and become a distraction or annoyance to the user if done too much: similar to the results from Microsoft's Clippy character.

A lot of effects and game components went unnoticed: such as the Turtle feedback. It was suggested that the Turtle become larger and an AI helper: pointing out butterfly locations or helping you catch them with a net. Dynamic environment was also suggested by participants to stop patients becoming bored or the 3D world stale/stagnant. Participants also suggested when increasing level difficulty to have more dynamic elements to the gameplay, such as: AI enemy who captures butterflies; variety of insects to catch with wasps and bees being markers to avoid' variety of particles, insects could move around on the screen and not be in fixed positions; sound effects and other game elements to avoid game stagnation if the game is to be part of a repetitive exercise rehabilitation regime.

Overall the game was found to be to a very high standard and professionally executed. Comments from participants were that it is commercially viable (game and the system) and could be sold right now. Participants commented on how they found the game to be fun, best experiment done, would be involved in future experiments. They also commented how they felt the various technologies were 'cool' and they could see the purpose behind each part of the experiment /research being undertaken.

11. Experiment 5: Online Evaluation

In this chapter, the researcher presents the results from the online experiments. These results include questionnaires and statistical information relevant to the experiment.

11.1. Evaluation Goals

The primary goal for the online experiment was to provide a means for healthcare professionals (primarily physiotherapists), patients and healthy individuals to carry out the adherence experiment and serious games experiment online. This approach also provided a means of establishing a community around the research project with forums for open discussion for communication between participants. The online experiments focused on the adherence experiment, especially which methods help the user follow commands better. The serious games online experiment also probed attributes such as depth perception, fun factor, and components that enhance the gameplay.

The research hypothesis is: *By providing an online environment for individuals to collaborate and be involved in research projects, they can work around their schedule and commitments to contribute to a research project.*

The null hypothesis is: *By providing an online environment for individuals to collaborate and be involved in research projects, they still will not be able to work around their schedule and commitments to contribute to a research project.*

11.2. Website Components

There are four main parts to the website (further information can be found in the Appendix) and they are as follows:

1. **Account Creation -** On the homepage of the website, there is the option to create a new account or login. Upon creating an account, the participant will have an activation email sent to them and will be automatically enrolled into the two courses.

2. **Two Courses -** The online and local user testing are represented as separate courses on the website.

3. **Demographics and Unlocking Hidden Sections -** The participants need to fill out the demographics form in the course they are participating in before they gain access to the rest of the questionnaires and games (only for the online user testing).

4. **Badges -** For the online participants, there are rewards in the forms of badges to encourage them to complete as much of the course as possible.

5. Forums - For the online participants, there are several different types of forums that they can use to interact with each other in a community setting.

6. **Time Table -** For the participants participating in the local user testing, there is a timetable which shows available time slots for user testing which they can book.

11.3. Experiment Design

An open end design was used for the experiment. This allowed users from any background to create an account for the website and participate in the online experiments. The main differences were in the serious games presented to the participants. The games, were adapted from the butterfly, adherence experiment games and Parkinson's games (developed earlier by the author). All games have been adapted to work in the Moodle environment that was used to create the website. All input is via the mouse and keyboard. All games are played via the web-browser.

The purpose of the online experiment, was to create a new method of collaboration between medical staff, patients and users with researchers. As mentioned in previous experiment chapters access and involvement with key target users is often not possible due to restrictions around resources and medical experiments.

The butterfly and adherence games are based on a similar approach to what has been presented in Chapters 6.4 and 9.4. The authors have kept to the method of reaching tasks with 10 butterflies needed to be collected for standard stroke game and 15 for adherence. The Marshmallow and Chicken mini game are based on timing and reaction tasks.

The Marshmallow game is a timing task. The participants have a 45 second countdown timer and have to score as many points as possible. They score points by cooking the perfect marshmallow. This is achieved by waiting for the marshmallow be to cooked for a certain number of seconds depending on level of difficulty chosen. There is visual feedback in both numbers and colour change of marshmallow. If left too long, it will burn and another marshmallow is chosen. Each marshmallow is chosen at random between five available options. There are four difficulty levels: Easy, Normal, Hard and Insane. The Easy, Normal and Hard levels all have the same gameplay; but the cooking speed on the marshmallows is faster. The Insane level, cooks the marshmallow faster and faster. The level ends once the participant burns a marshmallow.

The Chicken game is a reaction task. Participants have a 45 second countdown timer and have to score as many points as possible. They score points by collecting eggs that fall from the back of five chickens in a basket they control before the eggs hit the ground. Egg spawn points are chosen at random and are a mixture of good and bad eggs. The participant objective is to collect only the good eggs and avoid the bad eggs. Level difficulty is the same as described in the Marshmallow mini game. The difference being is that as you increase the difficulty, eggs fall faster, more bad eggs are likely to spawn and the spawning of eggs is increased compared to the Marshmallow mini game which can only have one cooking marshmallow at a time.

The phases in the experiment became available after the participant completed the demographics questionnaire. The phases in the experiment were:

1. **<u>Ghost:</u>** This phase was the adherence experiment for both patient and therapist.
2. **<u>Stroke Butterfly Game:</u>** This was the stroke rehabilitation serious game.
3. **<u>Medical Database:</u>** This was only available to medical staff and its purpose was to gain information around the type of information they would want to gather from a patient, how to store it and how to display that information to them.
4. **<u>Animal Friends:</u>** This phase was the Parkinson's games to see if these serious games have potential and could be adapted for other areas.

Participants

Twelve (12) participants(8 males, 4 females) with the average age was 33.92 enrolled into the online experiment from around the world. Information around the different game components was gained in the questionnaires the participants filled in. There was also a demographics section which reported on certain characteristics of the group being tested. They are as follows:

1. 9 of 12 participants have been involved in experiments before.
2. 7 of 12 participants have played serious games before.
3. 11 of 12 participants were comfortable with technology with 5 participants being Comfortable, 6 participants being Very comfortable and 1 participants being neutral.

Measurements
The gaming prototypes in this experiment were used to evaluate different representational and interaction constructs based on the following experimental measures:

1. Ranking of arm conditions conditions.
2. Qualitative questions on aspects of each serious game.
3. Questionnaires on the different components used to make the Butterfly Game.
4. Likert Scale evaluating various interface attributes.

The dependant variables for this experiment were:

1. Website - All participants are presented with the same information and process when they sign up for the online user testing.

The independent variables for the experiments are:

1. **Serious Games -** There are a certain number of serious games that need to be tested as part of the experiment.

Material and Procedures
The following materials were used to carry out the experiment:

1. Participants Computer
2. Internet A Desk and Chair
3. Webbrowser
4. Online Information Sheet

Participants were asked to complete questionnaires after each phase in the experiment. These questionnaires are shown in Appendix X. The participants were encouraged to complete as many parts of the experiment as possible. Subjects were given a written, video and diagram instructions on how to play the game and conduct each experiment. The participants were also given an overview of each phase in the experiment so that they were aware of how that part of the experiment should be done and how the serious games work. There was also a troubleshooting section should they get stuck.

Experimental Process
The process of the experiment was as follows:

1. Participants create an account on the website.
2. They confirm their email address to gain access to the online experiment: this was done to stop web bots and spam interfering with the online experiment and results.
3. Participants have the option to book a time slot for local user testing if they are in the Canterbury area.
4. Participant proceed to the online experiment labeled as the course: *Ghost - Online Testing.*
5. Participant fills in the demographics questionnaire to gain access to the other phases of the experiment.
6. Participants select phases of the experiment they would like to do.
7. Participants can use forums to ask questions or communicate with one another(forums, emails and messaging) in an online community manner.

This process is followed until all phases of the online experiment are completed with their corresponding questionnaires and feedback forms. As they progress through the online experiment, they are rewarded with badges as part of the Online Digital Badge Skill Set" which they can keep and show off to the world wide Internet as part of their Internet profile.

Pilot Testing
Pilot Test was conducted to find any bugs or obvious problems. There was several key problems that were found and rectified:

1. **Auto enrollment:** It was found that participants were not gaining immediate access to the online experiment or local experiment for booking a time slot. This was fixed with a plugin from the Moodle site and website settings.
2. **Time Table Bug:** There was a bug that showed the correct time slots for the researchers end but incorrect from the participants. This had to do with time zone of the server, timezone of the person who created the time slots: being the researcher, and timezone of the participant. Time zones were specified by what countries the users selected. This was fixed by forcing the time to a fixed time zone for all of the above.
3. **Questionnaires:** There was some errors in the questions in the questionnaire which were fixed.
4. **Troubleshooting:** A troubleshooting section was added to help online users navigate and understand the online experiment.

11.4. Results and Analysis

11.4.1. Results

From conducting the online experiment we have gained better insight into this approach in collaboration with users. Unfortunately, there was not enough feedback beyond the demographics section for meaningful results. The following sections explore the reasons for this.

11.4.2. Statistical Results from Experiment

There was not enough participants feedback to analysis anything meaningful.

Qualitative Feedback
There was not enough participants feedback to analysis anything meaningful other than what was presented in the previous section.

11.4.3. Threats to Validity

Feedback from a head physiotherapist at a health centre revealed some insight into why the online experiment didn't yield meaningful results in a way the local user testing has done. An unforeseen problem was identified.

As health care centers deal directly with medical data, there is a lot of protocols, protections and procedures in place to deal with the sensitive nature involved in handling such data. This makes a great deal of sense. But a by product of this approach is in the level of control the local user has on any given computer system. What was found from the online user testing was that the computers being used had outdated web browsers. It was unknown what web browser or version was being used, but it caused problems with the usability of the website in the text being somewhat difficult to read. This problem was not found outside the system being used. The participant was still able to do some phases of the experiment.

Another problem identified was in the installation of software, in this case, web browser plugins needed to run the serious games via the browser. Restrictions have been put in place by the IT department restricting for safety reasons. As such, this prevented the participants from watching the online videos or playing the serious games.

So based on the findings, it was found that equipment in the healthcare sector suffer from the following restraints:

1. **Old System -** Computer system in health care might be old technology but is suitable for the tasks required by the health care infrastructure.
2. **Outdated Software -** Web Browsers and other software on the computer systems may be outdated but fall within the task requirements of the healthcare IT infrastructure
3. **Restrictions -** Majority of users will not have permissions to install or update any software and will need to liaison with their IT department.

There are two solutions to the identified problems. They are:

1. **Personal Computers -** The easiest and most simplest solution is to have users use their personal computers to conduct the online experiments.
2. **Liaison with IT departments -** Collaboration with each health care center IT department is a solution but could require a large amount of time per health care center.

11.5. Discussion of Results

The creation of an online environment for collaboration did not yield significant results but did show the problems and shortcomings faced with such an experiment design. The author still views this means of collaboration as an area worth investigating. The reasons lays in access and recruitment of patients, medical staff and targeted users in general. Often, their time is limited and involvement in experiments is a lengthy and sometimes difficult process for any medical research.

Users using their own free will to join an online community to provide feedback and input could become a rich and useful resource. Some other solutions to health care computer systems have been outlined in the previous section. But another method could be private videos on YouTube or another video hosting site that is compatible with outdated systems. This could be used to provide video footage of experiments and serious games for the participants to then provide feedback.

For the online experiments, it would be beneficial to have an introduction video describing the research project, important parts of the website and what they hope to achieve from the participants involvement. This will help highlight phases or parts of the experiment that the researcher would deemed most valuable for feedback. It would also help remove any confusions around the experiment. A troubleshooting section and support email should still be used in addition to the introduction video.

Another useful approach would be to liaison with one medical staff per health care center. They can then encourage or pass on information around the research project to other medical staff. This will remove the confusion in contacting large groups, policies around involving medical staff and patients in experiments as you are not recruiting participants directly but just creating an online environment for a community to develop. The author feels such a tool or community would be invaluable to a research project as it would provide a means of tapping directly into a user and knowledge base.

12. Results: Lessons Learned

12.1. Results

This chapter discusses and integrates the results of the five experiments reported in Chapters 7-11.

12.2. Quantitative Results from Experiments 1-5

The following summarizes the findings from the time to completion experiments:

<u>Finding 1: Tracking</u>
From a tracking standpoint (while using the Large Display) the Kinect V2 was determined to be the lowest mean completion time; however this mean when compared with the completion times for the other tracking solutions (i.e. mouse, Kinect V1, and Flock) were not statistically significant except for Myo. The Kinect V2 was also the most favoured due to its ease of use and linking the participants real arm with the 3D arm.

What research questions does this answer?
Based on the evidence gained from the user experiments, we can answer some of the questions outlined in Chapter 6.

How easy was each of the tracking method to use? We have found that participants rated either of the Kinect as one of the easiest to use due to its natural gesture tracking. The mouse was found to be easy as well but this is a device participants are familiar with and interact with almost on a daily. The Myo was deemed the least easiest of the devices to use with participants find it unnatural in how they had to interact and move their bodies for gesture recognition.

Which methods of tracking provided the most enjoyment? Participants enjoyed using the either of the Kinect due to its natural gesture tracking and could focus on the task and not on the controls or input method.

Test each tracking solution in terms of accuracy? We found that the Kinect V2 had the lowest mean completion time compared to other tracking devices with Myo the longest.

Find the limitations of each tracking solution. We found that the Myo was the least favoured by participants due to difficulties they found in using the gestures.

What hypothesis does this prove?
This proves the hypothesis outlined in Chapter 7: *There is a difference in performance or usability between different input devices.* Which means we can reject the null hypothesis: *There is no difference in performance or usability between different input devices.*

Finding 2 Display
From a display standpoint (while using the Kinect V1) the Oculus reported the lowest mean completion time but was not significantly different from the other display approaches; however, the ranking by participants showed that the Oculus was statically significant in being favored as the best display.

What research questions does this answer?
Based on the evidence gained from the user experiments, we can answer some of the questions outlined in Chapter 6.

Which method helps the user feel more immersed in the Virtual World (sense of presence)? The Oculus was found to provide the highest level of immersion amongst the display devices tested.

How well the user can navigate and view the world without suffering from motion sickness (cybersickness)? The only occurrence of sickness or unease reported from participants was in the use of Vision Space 3D and Oculus. This number was fairly low and was caused in the Oculus when some participants moved their head around too fast. In the Vision Space it was caused by a mixture of 3D environment and 2D display.

How easy was each of the display methods to use? Participants found all display devices easy to use and their was no report in difficulties faced when using any of the devices.

Which methods of display provided the most enjoyment? Participants found the Oculus to be the most enjoyable. For a number of participants it was their first time experiencing the Oculus and that level of immersion in a virtual world. Participants did highlight that the Large Display was still ok to use, even though it was ranked least favoured.

What hypothesis does this prove?
This proves the hypothesis outlined in Chapter 8: *There is a difference in performance or usability between different display devices*. Which means we can reject the null hypothesis: *There is no difference in performance or usability between different display devices.*

Finding 3 Integrated tracking and display
The author found that combined with the best display, being the Oculus for its level of immersion, indicated the ideal system being Oculus and Kinect V2. The Myo Armband did cause a number of difficulties as an input device, not working on certain participants and causing physical pain in others, but its potential was still commented on by participants.

Finding 4: Adherence configuration
In the interaction constructs experiment, we found out that there needs to be two different arm types for collaboration to work between Therapist and Patient. Participants highlighted that two real arms in the same scene will not work as they both interfere with each other and cause confusion.

What research questions does this answer?
Based on the evidence gained from the user experiments, we can answer some of the questions outlined in Chapter 6.

What are the best methods for having instructions commands followed? In the simulated collaboration experiment on interaction constructs. It was found that there needs to be a visual difference between the 3D arms, otherwise it leads to confusion and frustration. The most favoured approach was the Ghost Occlusion visual effect when collaborating with 3D arms with no visual effects applied.

What hypothesis does this prove?
This proves the hypothesis outlined in Chapter 9: *There is a difference in performance or usability between different interaction constructs or special effects.* Which means we can reject the null hypothesis: *There is no difference in performance or usability between different interaction constructs or special effects.*

Finding 5: Imporatance of a minimap
In the reaching tasks, the mini map was found to be the main center of focus with the main screen acting as a secondary focus: in other words, the main screen and mini map roles were swapped around. Other techniques were also used, such as reaching all the way forward and catching the butterflies on the way back. But, all these techniques were only used in 2D displays and not in 3D.

Finding 6: Utility of 3D displays
It was found that 3D did not need the minimap feedback mechanics due to depth

perception being natural given as a by product of the technology.

What research questions does this answer?
Based on the evidence gained from the user experiments, we can answer some of the questions outlined in Chapter 6.

What components of teh game help with depth perception? It was found that in 2D display devices that the minimap was the most favoured and helpful in aiding depth perception. However, depth perception components were not needed in 3D display devices as participants found no need for them.

Finding 7: Collaboration time
The Online experiment revealed the need for further investigations on how to collaborate with target user groups where there is limited access or time available for collaboration. The experiment revealed the problems associated with hospital computers (admin permission rights and software versions) and follow through on completing phases of the experiments after signing up.

Finding 8: Patient Motivation:
Digital Badges were used as a form of motivation but other forms of engagement should be investigated, such as: a prize/competition or having a leader from each facility who helps other participants and encourages them with research involvement. These approaches could help create an online community. But it is deemed that such an undertaking, while extremely valuable, will also come with its share of challenges to create such a culture.

12.3. Qualitative Feedback

Finding 9: Technology to augment not replace therapists
Feedback from interviews among medical staff revealed the need to highlight that new rehabilitation technology such as Ghost is a tool for them and not a replacement.

Finding 10: Matching the therapy to the patient
Practitioners also highlighted that each patient is different and needs to be accessed by the medical staff before a rehabilitation program can be given to patients. However, they did believe that Ghost could be used as a tool to aid them in accessing a patient in a one on one scenario before the patient does home rehabilitation but not as an automated process they try by themselves. Therapists also requested the ability to monitor and change a patient's rehabilitation program based on their progress.

Finding 11: Wearing technology

Feedback from participants showed that the Kinect V2 was the most favoured tracking devices as they didn't have to wear anything on their bodies and it was just easy and natural to use. Some participants didn't find a difference between Kinect V1 and V2 while others commented on Kinect V2 as being faster. Participants did find the Myo to be the most difficult to use with a lot of negative comments being made.

This helps answer the research question: *How easy was each of the tracking methods to use?*

Finding 12: Head-mounted display

Contrary to Finding 11, the Oculus got a swarm of positive reviews with participants being amazed by the technology combined with the game world. this was highlighted by participants that the Large Display is not bad, it just doesn't offer or enhance the experience in anyway compared to the Oculus. Some participants did feel sick from the Oculus due to head tracking and low resolution but this number counted for a small percentage of the participants.

This helps answers the research question: *Which methods of display provide the most enjoyment?*

Finding 13: Gamification

Like Finding 8 the interaction constructs experiment found the patient game to be easier to play than the therapist when collaborating with the AI; the reason being is that the AI was helpful to a patient as you simply followed its movement path with no real issue on the type of effect you had on your arm. While the therapist if leading the AI patient, the other arm would block or get in the way of the location of the next reaching target (butterfly). This shows that the local user being real and the remote collaborator being a Ghost Occlusion effect might be the best approach. The local user is able to see what the remote collaborator is doing but it does not interfere with what the local user can see or do. Feedback on the game was positive for the purpose it was trying to achieve: reaching tasks.

What hypothesis does this prove?

This proves the hypothesizes: *Serious games can be used as a tool for the creation of rehabilitation exercise.* Which means we can reject the null hypothesis: *Serious games cannot be used as a tool for the creation of rehabilitation exercise.*

Finding 14: Automatic spatial feedback with 3D Display

There was no need for feedback mechanism when in 3D compared to 2D. 2D displays inherit a lot of difficulty in navigating a 3D environment due to depth perception being removed. This involves the need for additional feedback but in turns leads to multitasking and higher levels of concentration from the user. In

3D, depth is provided naturally. When using the Oculus, participants did find the static GUI to be cool as they felt they could reach out and touch it but also found that it being in a fixed position could block the participants view and what they were trying to achieve. The solution to this condition would be to have a GUI that moves with the user's head position and to have the GUI slightly transparent to avoid blocking part of their view.

This helps answer the research question: *Which method helps the user feel more immersed in the Virtual World(sense of presence)?*

Finding 15: Great feedback from participants in experiment
The quality and quantity of the feedback from participants was overwhelming. Overall they had a lot of fun during the experiment, so much so that they recruited their friends on their own accord so that they could talk to each other about their experience gained from undertaking the study. The main points of these experiences came from trying out various technologies, with the Oculus and Kinect V2 being at the forefront for the level of immersion combined with natural gestures and movements. Many highlighted that the Ghost experiments were the best they have ever done and volunteered themselves for future experiments without being asked. They commented on how they could understand the purpose behind each different experiment. Participants also didn't seem to mind the duration of the experiments due to how much fun they were having: some participants commented that it was the longest study they have been involved but that they were having fun.

This helps answer the research question: *Was the game fun and what was good and bad about it?*

Finding 16: Quality of serious game experience
Participants viewed the quality of the serious game and systems to be at a very high standard and that it to be commercially viable as is.

What hypothesis does this prove?
This proves the hypothesizes: *Serious games can be used as a tool for the creation of rehabilitation exercise.* Which means we can reject the null hypothesis: *Serious games cannot be used as a tool for the creation of rehabilitation exercise.*

Finding 17: Other rehabilitation applications
Participants made a number of suggestions. The main comments came in the form of other rehabilitation applications, research areas, game improvements and how to increase game difficulty levels. The suggestions for other areas and facilities are: leg rehabilitation for stroke or broken bones in learning how to walk again, children's hospitals, psychological state of the patient, tracking eye movements, wii fit like games, military simulator.

What hypothesis does this prove?
This proves the hypothesizes: *Serious games can be used as a tool for the creation of rehabilitation exercise.* Which means we can reject the null hypothesis: *Serious games cannot be used as a tool for the creation of rehabilitation exercise.*

Finding 18: Game improvements
The suggestions for game improvements and difficulty are: conflicting elements such as catching certain insects while avoiding others, competing against an AI who eats the butterflies, butterflies moving around, multiple butterflies at once, being able to spend your gold, sun in the game for shadows, tracking other body parts with the kinect, shoulder alignment into a more natural position, dynamic components and environment to keep patients engaged. Other game ideas were suggested such as collecting books in a library or making a recipe in a kitchen for reaching tasks. Suggested equipment came in the form of other types of Head Mounted Displays besides the Oculus.

This helps answer the research question: *Was the game fun and what was good and bad about it?*

12.3.1. Observations

Observations from all experiments viewed the Myo Armband as the tracking device causing the most difficulty. Using the Myo, participants ended up in strange positions with their bodies contorted in a similar manner to yoga poses. The other tracking devices seemed to cause no difficulties except the Flock of Birds in some cases and Kinect V1 and V2 when tracking was lost. Display devices had no real problems except the mixture of 2D GUI with 3D effects in the Vision Space 3D. Participants seemed to favour the Oculus due to the wow factor and high immersion levels but commented on how long they could remain immersed in such a system. One participant commented that 6 hours would be way too much and would depends on the task to be accomplished.

Interaction constructs experiment seen participant focusing on reaching tasks and not arm conditions. It was seen that the therapist did cause issues with the other arm getting in the way and patients commenting being the patient is easier as you just follow the other arm. This can be seen as a form of action observation treatment. The game seemed to full fill its role in reaching tasks with different techniques used depending on the display type. Interestingly, all techniques seem to vanish in 3D displays with the participant not using any feedback mechanics for depth perception. The game was played in a natural manner, with participant reaching out and grabbing butterflies as they would in real life.

12.3.2. Presentations

Feedback from presentations to various medical groups revealed that there was support for the creation of a new rehabilitation tool such as Ghost. Among other things it was clear that there was a need for audio communication between Therapist to Patient if collaborating remotely. Practical functional tasks (such as the ability to do everyday tasks such as picking up a cup) and recording Therapist exercises was a feature requested for patients at home rehabilitation via Ghost. Therapists also highlighted how they would like to record the patients movements in performing functional tasks to make sure they were being done correctly and without their body compensating (contorted in unusual ways) from the effects of the stroke.

12.4. Threats to Validity

Interaction Constructs experiment. There were also participants with prior experience with certain technology devices which may have influence their time completion and feedback given based on this experience: the mouse is an example of such experience being a common computer input device. A random and alternating order in the experiments avoided any unfair or unbalanced approach that may have occurred otherwise. However, it was highlighted multiple times by different participants, that they would like to go back and change their feedback given for certain conditions after experiencing others. The reason being is that their collective experience of the conditions changed how they would rate each condition. This desire to change their feedback was covered by the interview held at the end of the experiments. This interview recorded their preference in ranking of the conditions which can then be compared to the other statistics that were gathered.

12.5. Questions Unanswered

Several questions arose from undertaking the experiment that still need to be addressed.

12.5.1. How does grasp gestures affect the outcome of reaching tasks?

Although we have tested reaching tasks via the Butterfly game with varying devices what experience and outcome would happen from involving reaching task combined with grasping the reach targets instead of touching them? The level of difficulty for a patient would definitely be increase when combining two or more exercises, but foremost would be testing tracking or input of grasping tasks as an area of investigation.

12.5.2. Effects of different tracking and display devices on different medical conditions?

All participants in the experiment reported in this thesis have been healthy individuals with no severe medical conditions. It is worth investigating the affects of the selected devices from participants within the target users group: stroke survivors. It would also be a good investigate how the different devices work for different rehabilitation conditions; for example, kinect tracking might be better for stroke patients while physical devices (buttons or hand held objects) are better for Parkinson's patients.

12.5.3. Collaboration between real users?

Currently the interaction constructs experiment was conducted with a participant working together with an AI program to complete reaching tasks. It is worth investigating collaboration between two human participants in completing reaching tasks with the arm conditions that were selected as the best candidates by participants.

12.5.4. AR mode for Ghost?

Currently the Ghost system for collaboration has been tested in an external VR 3D environment. It is worth investigating the effects of overlaying the same 3D tracking data over the users body so that the local user is collaborating with an object that appears on top of their body as it is viewed in a real world setting.

12.6. Results Summary

From the quantitative, qualitative and observational results gathered from the experiments described above, the Kinect V2 for tracking, Head Mounted Display for viewing, local user as Real Arm Condition with collaborator being Ghost Occlusion Arm Condition is the possibly the best combination of technologies and configurations for further investigation into the Ghost project. The stroke butterfly game also has potential as a userful rehabilitation paradigm for stroke reaching tasks.

A walk through video of the experiment room can be found here:
Ghost Lab Setup (http://youtu.be/BNMQXaJMTsY)

A voice over of the experiments conducted as part of the research project can be found here:
Ghost Overview (http://youtu.be/5lHLi1MB04U)

The document submitted outlining user experiments for ethics approval can be found here:
Ghost Experiment Ethics
(https://app.box.com/s/0atvkqvmlraofynerex3g4y2hk1mpl8z)

13. Conclusion and Future Work

13.1. Conclusion

This research has provided a solid foray into a new concept for rahbilitation therapy with technical insight into the different tracking devices, display devices, interaction construct types with Arm conditions and serious game for rehabilitation exercise on reaching tasks.

Based on the research findings reported herein across the candidate technologies and independent variables, the author concludes that the combination of the Kinect V2, Oculus Head Mounted Display, local user Real Arm Condition and Collaborator Ghost Occlusion Arm Condition are supported as being the most favoured Ghost configuration for collaboration between Therapist and Patient. The Butterfly game has also been shown to have potential in providing a means to conduct reaching tasks as part of a rehabilitation program for stroke survivors. Findings also support the potential of using the stroke template to help guide serious games being developed for reaching tasks.

By integrating the components above we can configure a prototype system for testing the basis of the Ghost concept in a clinical setting. Based on feedback from participants who have undertaken the experiments and feedback frompresentations given to medical groups, the Ghost concept research shows enormous potential as a rehabilitation tool for stroke patients. This is especially significant in addressing the needs of an aging population, rise in medical conditions and limitations of available resources. Ghost is a solution in the growing battle to combat the demand placed on the healthcare sector to increase output and quality of medical staff. Ghost is also a boon to patients, as it can potentially afford quality physiotherapy while at home.

Nevertheless, the proof of the efficacy of the Ghost lies in accomplishing Phase 2 of the effort to take the ideal configuration reported above into clinical field trials, wherein the true test of the viability of this approach can be assess for the target community. Further research should also be performed in optimizing the technology, constructs and gamification. Research and collaboration with the healthcare sector is always at the forefront of this research project. Other components of Ghost are also needed, such as a medical database and a series of rehabilitation tasks. These components will all need to be researched, designed and evaluated before they are integrated into the Ghost. But based on the current research and feedback, the future of Ghost looks bright with a positive impetus from this research to continue research and test validation.

13.2. Contributions

The Ghost concept, its configuration and utility for stroke rehabilitation therapy through gamification is original. The author has adapted, configured and programmed commercial off-the-shelf components with an enormous effort to make them work together, but most especially to provide an interface via representational and interaction constructs that make the technology intuitive and viable for human consumption, especially for rehabilitation.

Additionally the author has developed a way to evaluate and trade-off these technologies and for the first time, provide answers to the general research questions presented in Chapter 4

13.3. Future Research

The author desires to continue developing and evaluating the Ghost concept. There are essential components that still need to be created, designed and integrated. But the most important step is to evaluate the optimized Ghost configurations in a clinical setting.

One area specifically that needs to be trialed is the feedback of target users from using the current Ghost system involving both Therapists and stroke patients as well as other medical staff and types of patients. Further, Ghost will also need to test the concept of overlaying another persons body on top of their own in an Augmented Reality view and not in an external 3D environment.

Rehabilitation exercises need to be investigated. This includes the ability of a Therapist to record their movements and have it turned into a rehabilitation exercise to assess patients' condition and rehabilitation progress. There are a myriad of serious games that need to be created for motivation and retention. There are functional tasks that need to be created as a form of assessment to judge patients progress.

The author also envisions the need to a therapy network for online activity of therapy sessions and automatic database generation or a method of storing patient data along with its analysis. This is a requirement so a Therapist can monitor patient progress and assign their rehabilitation protocol. In the final stages, handling of patient data will need to be worked closely with the healthcare sector and Government to ensure patient data is protected and standards met.

One area which the author investigated but did not report is that of the technology cost tradeoffs versus effectiveness. Further work is needed to investigate the life cycle cost of using Ghost-type therapy versus traditional means. Such an analysis will by necessity delve into the cost of time and throughput for therapists using traditional versus advanced methods such as Ghost. Only in this way can a case be made that investment in the Ghost can have an enormous impact on affordable healthcare, especially for an ageing population.

Ghost will need to have a *Health Console designed.* This will be the system that goes into patients and Therapist environment that provides access to a *Health App Store*. The *Health App Store* is a digital store that permits game developers to create serious games for patients to access. This will allow Therapists to recommend certain games or rehabilitation exercise types for a patient to play. For this to happen, a *Health Plugin* needs to be made available for game developers and include support for making games for the digital *Health Store* as well as provide support and guidelines in how to make serious games to the required standard. The plugin will also include support for the *Add-on Devices* that work with the *Health Console*. The *Add-On Devices* Devices are a means by which the cost of the *Health Console* is kept down. So a Therapist might be dealing with a stroke rehabilitation program that requires the patent (or government) to purchase a kinect type device to be able to use the rehabilitation program designed for them. Another patient might need to buy a physical controller device for their rehabilitation program. By this means, the *Health Console* cost can be kept down while still providing the level of care needed for different patient needs. All of the data collected will be stored via a *Cloud Service* that works with a database or servers possibly controlled by the Government (see previous paragraph). Game developers will not be able to identify patient details. They will only be able to save and retrieve information to the database via special methods. How this data is viewed for a Therapist will need to be investigated. It can be a secure application that is distributed only to medical staff or a cloud based service such as a web portal.

For all these reasons, working with Ghost is just beginning.

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A. Questionnaires

Ghost - Local User Testing in Christchurch

User Background

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There are required fields in this form marked *.

(Ethnicity) What ethnicity do you belong to?* (Position:1)

(Born) What country were you born in?* (Position:2)

(handPreference) Are you right or left handed(dominate hand)?* (Position:3)

- Right Hand
- Left Hand

(Health) Do you have or experienced any health condition(eg stroke, parkinsons disease etc)?* (Position:4)

- Yes
- No

(HealthConditions) What health conditions have you experienced? (Health->Yes) (Position:5)

Tuesday, 3 February 2015, 11:16 PM

(HealthSector) What Category would you place yourself in the Health Sector? (Position:6)

- Medical Staff
- Patient

- Healthy Individual

(Sex) Are you Male or Female? (Position:7)

- Male
- Female

(Age) How old are you* (10 - 100) (Position:8)

(Internet) Do you have access to the internet in a home environment? (Position:9)

- Yes
- No

(OnlineLearning) Have you ever used an online learning environment before(commonly used Universities)?* (Position:10)

- No
- Yes

(Games) Do you play computer Games?* (Position:11)

- No
- Yes

(GamingDevice) What devices do you play your games on?* (Games->Yes) (Position:12)

- Mobile Phone
- Tablet
- PC
- Game Console

(HoursOnGames) How many hours a week do you spend playing games?* (Games->Yes) (0 - 0) (Position:13)

(SeriousGames) Have you ever played a serious game before(education games, games for health etc)?* (Position:14)

- No
- Yes

(SeriousGameType) What type of serious games did you play(description if you cannot remember the name)?* (SeriousGames->Yes) (Position:15)

(Technology) How comfortable are you with technology(mobile phones, pc's etc)?* (Position:16)

- (1) Not Very comfortable

(1) Not very comfortable
- (2) Uncomfortable
- (3) Neutral
- (4) Comfortable
- (5) Very Comfortable

(UserStudies) Have you ever been involved in experiments(user studies) before?* (Position:17)

- No
- Yes

(TrainingSystems) What is your level of experience with training systems?* (Position:18)

- (1) Never used them
- (2) Have used them once before
- (3) Have used them a few times
- (4) Use them frequently

(ExtraInformation) Is there anything else we should know about you or that you want to tell us? (Position:19)

Ghost - Local User Testing in Christchurch

Mouse

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There are required fields in this form marked *.

Mouse (Position:1)

(Mouse) Have you ever used a Mouse before?* (Position:2)

- No
- Yes

(EaseOfUse) How easy was the device to use?* (Position:3)

- (1) Very Difficult
- (2) Difficult
- (3) Neutral
- (4) Easy
- (5) Very Easy

(Natural) How natural was the device to use?* (Position:4)

- (1) Very Natural
- (2) Natural
- (3) Neutral
- (4) Not Natural
- (5) Not Natural at all

(FunFactor) What was the fun factor like when using the device?* (Position:5)

- (1) Wasn't fun to use
- (2) Not too that bad
- (3) Neutral
- (4) Somewhat Fun to use
- (5) Really Fun to use

Page break (Position:6)

The System Usability Scale (Position:7)

(SystemUse) I think that I would like to use this system frequently.* (Position:8)

- (1) Strongly Disagree
- (2) 2
- (3) 3
- (4) 4
- (5) Strongly Agree

(Complex) I found the system unnecessarily complex.* (Position:9)

- (1) Strongly Disagree
- (2)
- (3)
- (4)
- (5) Strongly Agree

(EasyToUse) I thought the system was easy to use.* (Position:10)

- (1) Strongly Disagree
- (2)
- (3)
- (4)
- (5) Strongly Agree

(TechSupport) I think that I would need the support of a technical person to be able to use this system.* (Position:11)

- (1) Strongly Disagree
- (2)
- (3)
- (4)
- (5) Strongly Agree

(5) Strongly Agree

(SystemFunctions) I found the various functions in this system were well integrated.* (Position:12)

- (1) Strongly Disagree
- (2)
- (3)
- (4)
- (5) Strongly Agree

(Consistency) I thought there was too much inconsistency in this system.* (Position:13)

- (1) Strongly Disagree
- (2)
- (3)
- (4)
- (5) Strongly Agree

(LearningCurve) I would imagine that most people would learn to use this system very quickly.* (Position:14)

- (1) Strongly Disagree
- (2)
- (3)
- (4)
- (5) Strongly Agree

(Cumbersome) I found the system very cumbersome to use.* (Position:15)

- (1) Strongly Disagree
- (2)
- (3)
- (4)
- (5) Strongly Agree

(Confident) I felt very confident using the system.* (Position:16)

- (1) Strongly Disagree
- (2)
- (3)
- (4)
- (5) Strongly Agree

(TechingSystemControls) I needed to learn a lot of things before I could get going with this system.* (Position:17)

- (1) Strongly Disagree
- (2)
- (3)
- (4)
- (5) Strongly Agree

Ghost - Local User Testing in Christchurch

Large Display

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Preview

There are required fields in this form marked *.

Large Display (Position:1)

(LargeDisplay) Have you ever used a Large Display before?* (Position:2)

- No
- Yes

Yes

(EaseOfUse) How easy was the device to use?* (Position:3)

- (1) Very Difficult
- (2) Difficult
- (3) Neutral
- (4) Easy
- (5) Very Easy

(Natural) How natural was the device to use?* (Position:4)

- (1) Very Natural
- (2) Natural
- (3) Neutral
- (4) Not Natural
- (5) Not Natural at all

(FunFactor) What was the fun factor like when using the device?* (Position:5)

- (1) Wasn't fun to use
- (2) Not too that bad
- (3) Neutral
- (4) Somewhat Fun to use
- (5) Really Fun to use

(immersed) How immersed did you feel within the 3D world?* (Position:6)

- (1) Not very
- (2)
- (3)
- (4)
- (5) Very Immersed

(Perception) How much did this display method help with 3D depth perception in the 3D World?* (Position:7)

- (1) Didn't help at all
- (2)
- (3)
- (4)
- (5) Helped a lot

Page break (Position:8)

The System Usability Scale (Position:9)

(SystemUse) I think that I would like to use this system frequently.* (Position:10)

- (1) Strongly Disagree
- (2)
- (3)
- (4)

(5) Strongly Agree

(Complex) I found the system unnecessarily complex.* (Position:11)

- (1) Strongly Disagree
- (2)
- (3)
- (4)
- (5) Strongly Agree

(EasyToUse) I thought the system was easy to use.* (Position:12)

- (1) Strongly Disagree
- (2)
- (3)
- (4)
- (5) Strongly Agree

(TechSupport) I think that I would need the support of a technical person to be able to use this system.* (Position:13)

- (1) Strongly Disagree
- (2)
- (3)
- (4)
- (5) Strongly Agree

(SystemFunctions) I found the various functions in this system were well integrated.* (Position:14)

- (1) Strongly Disagree
- (2)
- (3)
- (4)
- (5) Strongly Agree

(Consistency) I thought there was too much inconsistency in this system.* (Position:15)

- (1) Strongly Disagree
- (2)
- (3)
- (4)
- (5) Strongly Agree

(LearningCurve) I would imagine that most people would learn to use this system very quickly.* (Position:16)

- (1) Strongly Disagree
- (2)
- (3)
- (4)
- (5) Strongly Agree

(Cumbersome) I found the system very cumbersome to use.* (Position:17)

- (1) Strongly Disagree

(1) Strongly Disagree
- (2)
- (3)
- (4)
- (5) Strongly Agree

(Confident) I felt very confident using the system.* (Position:18)

- (1) Strongly Disagree
- (2)
- (3)
- (4)
- (5) Strongly Agree

(TechingSystemControls) I needed to learn a lot of things before I could get going with this system.* (Position:19)

- (1) Strongly Disagree
- (2)
- (3)
- (4)
- (5) Strongly Agree

Ghost - Local User Testing in Christchurch

Patient Adherence Questionnaire

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Preview

There are required fields in this form marked *.

Real Arm (Position:1)

(RealTherapist) How easy was it to follow with Real arm Patient to movements(commands) of Real arm Therapist?* (Position:2)

- (1) Very Difficult
- (2) Difficult
- (3) Neutral
- (4) Easy
- (5) Very Easy

Ghost Arm (Position:3)

(GhostTherapist) How easy was it to follow with Ghost arm Patient to movements(commands) of Real arm Therapist?* (Position:4)

- (1) Very Difficult
- (2) Difficult
- (3) Neutral
- (4) Easy
- (5) Very Easy

Occlusion Arm (Position:5)

(OcclusionTherapist) How easy was it to follow with Occlusion arm Patient to movements(commands) of Real arm Therapist?* (Position:6)

- (1) Very Difficult
- (2) Difficult
- (3) Neutral
- (4) Easy
- (5) Very Easy

Colour Arm (Position:7)

(ColourTherapist) How easy was it to follow with Colour arm Patient to movements(commands) of Real arm Therapist?* (Position:8)

- (1) Very Difficult
- (2) Difficult
- (3) Neutral
- (4) Easy
- (5) Very Easy

Ghost Occlusion Arm (Position:9)

(GhostOcclusionTherapist) How easy was it to follow with Ghost & Occlusion arm Patient to movements(commands) of Real arm Therapist?* (Position:10)

- (1) Very Difficult
- (2) Difficult
- (3) Neutral
- (4) Easy
- (5) Very Easy

(Choice) Which is the most suited Ghost effect for the Patient(someone following or (Position:11) being guided by another person) to have?*

- Real Arm
- Ghost Arm
- Occlusion Arm
- Colour Arm
- Ghost and Occlusion Arm

Ghost - Local User Testing in Christchurch

Gameplay Questionnaire Feedback

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Preview

There are required fields in this form marked *.

Butterfly Game (Position:1)

(Artwork) Was the artwork in the game to a high enough standard?* (Position:2)

- (1) Strongly Agree
- (2) Agree
- (3) Neutral
- (4) Disagree
- (5) Strongly Disagree

(Gameplay) Was the gameplay fun?* (Position:3)

- (1) Strongly Disagree
- (2) Disagree
- (3) Neutral
- (4) Agree
- (5) Strongly Agree

(Feedback) How effective was the feedback in the game to tell you how well you were doing[sound effects, particles, pop up message etc]?* (Position:4)

- (1) Very Effective
- (2) Effective
- (3) Neutral
- (4) Not Effective

(5) Not Very effective

(Instructions) How easy was it to understand the gameplay?* (Position:5)

(1) Very Difficult
(2) Difficult
(3) Neutral
(4) Easy
(5) Very Easy

(Good) What aspect,if any, was good? (Position:6)

(Bad) What aspect,if any, was bad? (Position:7)

(Area) What other area is this game suitable for e.g children's hospital? (Position:8)

(Modifications) What modifications would have to be made, if any, for the above areas? (Position:9)

Ghost - Local User Testing in Christchurch

Depth Perception Questionnaire Feedback

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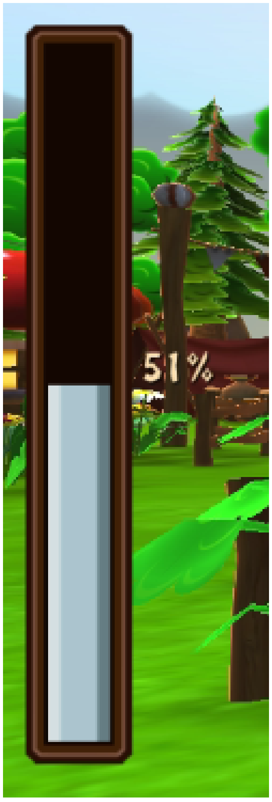
There are required fields in this form marked *.

Reach Gauge (Position:1)



(Effective) How effective was the Reach Gauge in showing depth?* (Position:2)

- (1) Very Effective
- (2) Effective

(2) Effective
(3) Neutral
(4) Not Effective
(5) Not Very effective

(EnhancedGameplay) Did the Reach Gauge enhance gameplay?* (Position:3)

(1) Strongly Disagree
(2) Disagree
(3) Neutral
(4) Agree
(5) Strongly Agree

(Good) What aspect, if any, was good? (Position:4)

(Bad) What aspect if any was bad? (Position:5)

(Improvement) What could be done to improve? (Position:6)

Page break (Position:7)

Mini Map (Position:8)

(Effective) How effective was the Mini Map in showing depth?* (Position:9)

- (1) Very Effective
- (2) Effective
- (3) Neutral
- (4) Not Effective
- (5) Not Very effective

(EnhancedGameplay) Did the Mini Map enhance gameplay?* (Position:10)

- (1) Strongly Disagree
- (2) Disagree
- (3) Neutral
- (4) Agree
- (5) Strongly Agree

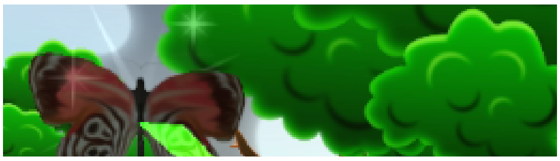
(Good) What aspect, if any, was good? (Position:11)

(Bad) What aspect if any was bad? (Position:12)

(Improvement) What could be done to improve? (Position:13)

Page break (Position:14)

Line Render (Position:15)



(Effective) How effective was the Line Rener in showing depth?* (Position:16)

- (1) Very Effective
- (2) Effective
- (3) Neutral
- (4) Not Effective
- (5) Not Very effective

(EnhancedGameplay) Did the Line Render enhance gameplay?* (Position:17)

- (1) Strongly Disagree
- (2) Disagree
- (3) Neutral
- (4) Agree
- (5) Strongly Agree

(Good) What aspect, if any, was good? (Position:18)

(Bad) What aspect if any was bad? (Position:19)

(Improvement) What could be done to improve? (Position:20)

Page break (Position:21)

Arm Shadow Cursor (Position:22)

(Effective) How effective was the Arm Shadow in showing depth?* (Position:23)

- (1) Very Effective
- (2) Effective
- (3) Neutral
- (4) Not Effective
- (5) Not Very effective

(EnhancedGameplay) Did the Arm Shadow enhance gameplay?* (Position:24)

- (1) Strongly Disagree
- (2) Disagree
- (3) Neutral
- (4) Agree
- (5) Strongly Agree

(Good) What aspect, if any, was good? (Position:25)

(Bad) What aspect if any was bad? (Position:26)

(Improvement) What could be done to improve? (Position:27)

Page break (Position:28)

Collected Butterfly Particles[Diamonds] (Position:29)

(Effective) How effective was the Particles in showing that you have reached the correct depth?* (Position:30)

- (1) Very Effective
- (2) Effective
- (3) Neutral
- (4) Not Effective
- (5) Not Very effective

(EnhancedGameplay) Did the Particles enhance gameplay?* (Position:31)

- (1) Strongly Disagree
- (2) Disagree
- (3) Neutral
- (4) Agree
- (5) Strongly Agree

(Good) What aspect, if any, was good? (Position:32)

(Bad) What aspect if any was bad? (Position:33)

(Improvement) What could be done to improve? (Position:34)

Ghost - Local User Testing in Christchurch

Game Mechanics Questionnaire Feedback

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There are required fields in this form marked *.

Butterfly Model (Position:1)

(Effective) How effective was the Butterfly as a target?* (Position:2)

- (1) Very Effective
- (2) Effective
- (3) Neutral
- (4) Not Effective
- (5) Not Very effective

(EnhancedGameplay) Did the butterfly markers enhance the gameplay?* (Position:3)

- (1) Strongly Disagree
- (2) Disagree
- (3) Neutral
- (4) Agree
- (5) Strongly Agree

(Good) What aspect,if any, was good? (Position:4)

(Bad) What aspect,if any, was bad? (Position:5)

(Improvement) What could be done to improve? (Position:6)

Page break (Position:7)

Arm Model (Position:8)

(Effective) How effective was the Arm 3D model in representing your real arm?* (Position:9)

- (1) Very Effective
- (2) Effective
- (3) Neutral
- (4) Not Effective
- (5) Not Very effective

(EnhancedGameplay) Did the Arm model enhance the gameplay?* (Position:10)

- (1) Strongly Disagree
- (2) Disagree
- (3) Neutral
- (4) Agree
- (5) Strongly Agree

(Good) What aspect,if any, was good? (Position:11)

(Bad) What aspect,if any, was bad? (Position:12)

(Improvement) What could be done to improve? (Position:13)

Page break (Position:14)

Butterfly Shadow Cursor (Position:15)

(Effective) How effective was the Butterfly Shadow in gauging Butterfly location?* (Position:16)

- (1) Very Effective
- (2) Effective
- (3) Neutral
- (4) Not Effective
- (5) Not Very effective

(EnhancedGameplay) Did the Butterfly Shadow enhance the gameplay?* (Position:17)

- (1) Strongly Disagree
- (2) Disagree
- (3) Neutral
- (4) Agree
- (5) Strongly Agree

(Good) What aspect,if any, was good? (Position:18)

(Bad) What aspect,if any, was bad? (Position:19)

(Improvement) What could be done to improve? (Position:20)

Page break (Position:21)

Spawn Particles (Special Effects[Sparkles] when butterfly appears) (Position:22)

(Effective) How effective was the spawn particles?* (Position:23)

- (1) Very Effective
- (2) Effective
- (3) Neutral
- (4) Not Effective
- (5) Not Very effective

(EnhancedGameplay) Did the spawn particles enhance the gameplay?* (Position:24)

- (1) Strongly Disagree
- (2) Disagree
- (3) Neutral
- (4) Agree
- (5) Strongly Agree

(Good) What aspect,if any, was good? (Position:25)

(Bad) What aspect,if any, was bad? (Position:26)

(Improvement) What could be done to improve? (Position:27)

Page break (Position:28)

Score Particles (Special Effects[Sparkles] that show when a Butterfly is collected) (Position:29)

(Effective) How effective was the score particles?* (Position:30)

- (1) Very Effective
- (2) Effective
- (3) Neutral
- (4) Not Effective
- (5) Not Very effective

(EnhancedGameplay) Did the score particles enhance the gameplay?* (Position:31)

- (1) Strongly Disagree
- (2) Disagree
- (3) Neutral
- (4) Agree
- (5) Strongly Agree

(Good) What aspect,if any, was good? (Position:32)

(Bad) What aspect,if any, was bad? (Position:33)

(Improvement) What could be done to improve? (Position:34)

Page break (Position:35)

Spawn Message (Words that appear on the screen when a Butterfly marker appears) (Position:36)

(Effective) How effective was the Spawn message?* (Position:37)

- (1) Very Effective
- (2) Effective
- (3) Neutral
- (4) Not Effective
- (5) Not Very effective

(EnhancedGameplay) Did the spawn message enhance the gameplay?* (Position:38)

- (1) Strongly Disagree
- (2) Disagree
- (3) Neutral
- (4) Agree
- (5) Strongly Agree

(Good) What aspect,if any, was good? (Position:39)

(Bad) What aspect,if any, was bad? (Position:40)

(Improvement) What could be done to improve? (Position:41)

Page break (Position:42)

Collected Message (The words that appear on the screen when a Butterfly is collected) (Position:43)

(Effective) How effective was the collected message?* (Position:44)

- (1) Very Effective
- (2) Effective
- (3) Neutral
- (4) Not Effective
- (5) Not Very effective

(EnhancedGameplay) Did the Collected Message enhance the gameplay?* (Position:45)

- (1) Strongly Disagree
- (2) Disagree
- (3) Neutral
- (4) Agree
- (5) Strongly Agree

(Good) What aspect,if any, was good? (Position:46)

(Bad) What aspect,if any, was bad? (Position:47)

(Improvement) What could be done to improve? (Position:48)

Page break (Position:49)

Sound Effects (Position:50)

Success: Success Sound.wav

Failure: Failure Sound.wav

End of Game: End of Game Sound.wav

(Effective) How effective was the sound effects?* (Position:51)

- (1) Very Effective
- (2) Effective
- (3) Neutral
- (4) Not Effective
- (5) Not Very effective

(EnhancedGameplay) Did the sound effects enhance the gameplay?* (Position:52)

- (1) Strongly Disagree
- (2) Disagree
- (3) Neutral
- (4) Agree
- (5) Strongly Agree

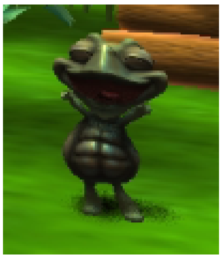
(Good) What aspect,if any, was good? (Position:53)

(Bad) What aspect,if any, was bad? (Position:54)

(Improvement) What could be done to improve? (Position:55)

Page break (Position:56)

Turtle Feedback (Position:57)



(Effective) How effective was the Turtle Feedback?* (Position:58)

- (1) Very Effective
- (2) Effective
- (3) Neutral
- (4) Not Effective
- (5) Not Very effective

(EnhancedGameplay) Did the Turtle Feedback enhance gameplay?* (Position:59)

- (1) Strongly Disagree
- (2) Disagree
- (3) Neutral
- (4) Agree
- (5) Strongly Agree

(Good) What aspect,if any, was good? (Position:60)

(Bad) What aspect,if any, was bad? (Position:61)

(Improvement) What could be done to improve? (Position:62)

Ghost - Local User Testing in Christchurch

Performance Feedback Questionnaire

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There are required fields in this form marked *.

Reach Target Number (Position:1)

(Effective) How effective was the Reach Target Number in showing performance?* (Position:2)

- (1) Very Effective
- (2) Effective
- (3) Neutral
- (4) Not Effective
- (5) Not Very effective

(EnhancedGameplay) Did the Reach Target Number enhance gameplay?* (Position:3)

- (1) Strongly Disagree
- (2) Disagree
- (3) Neutral
- (4) Agree
- (5) Strongly Agree

(Good) What aspect, if any, was good? (Position:4)

(Bad) What aspect if any was bad? (Position:5)

(Improvement) What could be done to improve? (Position:6)

Page break (Position:7)

Clock (Position:8)

(Effective) How effective was the Clock in showing performance?* (Position:9)

- (1) Very Effective
- (2) Effective
- (3) Neutral
- (4) Not Effective
- (5) Not Very effective

(EnhancedGameplay) Did the Clock enhance gameplay?* (Position:10)

- (1) Strongly Disagree
- (2) Disagree
- (3) Neutral
- (4) Agree
- (5) Strongly Agree

(Good) What aspect, if any, was good? (Position:11)

(Bad) What aspect if any was bad? (Position:12)

(Improvement) What could be done to improve? (Position:13)

Page break (Position:14)

Results Table (Position:15)

(Effective) How effective was the Results Table in showing performance?* (Position:16)

- (1) Very Effective
- (2) Effective
- (3) Neutral
- (4) Not Effective
- (5) Not Very effective

(EnhancedGameplay) Did the Results Table enhance gameplay?* (Position:17)

- Not selected
- (1) Strongly Disagree
- (2) Disagree
- (3) Neutral
- (4) Agree
- (5) Strongly Agree

(Good) What aspect, if any, was good? (Position:18)

(Bad) What aspect if any was bad? (Position:19)

(Improvement) What could be done to improve? (Position:20)

^

Ghost - Local User Testing in Christchurch

Gathering Information

Overview | Edit questions | Templates | Analysis | Show responses | Show non-respondents

Content

Select

Preview

There are required fields in this form marked *.

Gathering Information (Position:1)

(Ideas) Do you have any game ideas or general suggestions?* (Position:2)

(Equipment) What Equipment, if any, would you like to see being used? (Position:3)

(Exercise) What rehabilitation exercises or training program, if any, would you like to see made? (Position:4)

B. Structured Interview

Meeting with Marcus King

Background of thesis project for Marcus:

Ghost Background

Ghost is trying to allow rehabilitation exercises for musculoskeletal disorders at home. The unique concept is allowing a therapist to see through the eyes of his patient and vice versa. In this way the patient can follow along with what the therapist wants them to do as they will see the therapist body as a ghost overlay on top of their own.

When the therapist is not available. The patient can follow along to pre-recorded movements or undergo a series of serious games that have been based on rehabilitation exercises. Patients performance and progress are monitored and recorded which the therapist can view at any time.

An algorithm as part of the training mode will allow for calibration at the start or their rehabilitation to adjust the difficulty of the serious games and exercises. It will also adjust the difficulty of the games over time as the patient improves in their condition. The therapist at any time can also adjust these settings remotely.

This system also has the possibilities to be used for remote training, sport athletes, remote assistance etc

Current System plan

The current system is to use 2 kinect2 for tracking the users body. There will also be 2 HMD(Oculus) for a display system. We are also looking into the option of camera addons to allow for AR mode so the users don’t trip over.

The system will also be tested for different tracking solutions/performance:

1. VisionSpace Tracking
2. Flock of Birds
3. SixSense
4. Kinect1

The system will also be tested for different display solutions;

1. HMDs
    a. Oculus
    b. Totem
2. 2D screens
3. VisionSpace

The current idea is to test with healthy individuals tracking the users right arm. User_A will follow onscreen commands - acting as the therapist. User_A ghost will act as the commands for User_B.

The current plan experiments are:

1. Tracking and Display system
   a. Tracking data will be used to see which systems track better and what type of systems/rehabilitation they are best suited for.
2. User experiment following a pre-recorded ghost
   a. Just want to test how well a healthy individual can follow the ghost
3. User experiment with therapist and patient
   a. This will be healthy individuals being actors of the roles: therapist and patient
   b. This is to test how well a healthy individual can follow the commands of another person
   c. It will also test to see how the collaboration side of the system

Questions for Marcus:

Gamification

How do you go about creating a serious game or application for clinical use.

1. Visual Cues
2. Auditory Cues
3. Performance Measurements
    a. Highscores
    b. Combos
4. Success vs Failure
    a. Motivation
    b. Depression
    c. Failure seen as a bad thing
5. Scoring Algorithm
    a. Adjusting settings for clinicians
        i. reaction time
        ii. game length
        iii. error margin
6. Transferring exercises into the game
7. Patients vs Patients
8. Patients vs Healthy individuals(family members/friends)

Users Mood/Emotions

After reading some research papers, it seems depression is a common problem among stroke survivors with little or no motivation to do repetitive exercises.

Do you record or monitor the patients emotion as a factor of their performance or change the game or exercise difficulty based on their mood.

Type of data recorded

What types of data do you record from the patient?
What types of data do Clinicians want?
What type of data do you keep for patients to see their progress?

Diagnostic Tool

Virtual Reality has been used as a diagnostic tool to detect neglect in stroke survivors. Have you used or created any tools to help with diagnostics on patients?

How would such a thing be implemented?

Evaluation Tool

Virtual Reality has also been used to evaluate a patient's conditions. Its similar to a diagnostic tool but its more about testing their performance from when they first started their treatment. Even just monitoring on a daily basis(could be seen as progress or data collection).

Built in Clinical Tests

This can be linked to diagnostic tools and evaluation tools. But its asking if there is any implement virtual reality tests that are matching the clinical tests?
Some virtual reality tests, for example, could be made up just to test reaction speed or task completion time but might not be what clinicals test patients on in the real world.

Auto Calibration

Due to the various different conditions that patients are in, do you implement a auto calibration step. This could be part of the training mode.
Or
Is it a one size fits all or that they progress over time, so its set a fixed intervals.

Stroke patients vs other patients - considerations

Is there anything different you do for different types of conditions i.e
Stroke vs Parkinson Disease

Rehabilitation and VR systems

How does your current systems fit into the patient's life?
Is it a replacement for there exercises?
Are the games based on the exercises?
Is the patient doing exercises along the VR system?
Are they receiving any other treatment or medication?
Do they only use the systems at the health care providers or is it a home built system?
Length of the treatment or use of the VR system on a timeline? How many weeks, how often they use the system etc.

Assumptions and Personas

What should I be aware of when creating any sort of health application or serious game?
Are there any assumptions I can make about what to implement or expect a patient or clinician needs?
Do you use personas or any form of design process for creating your applications?
What are the most common forms of strokes or disorders? Age, gender, background(job occupation) etc

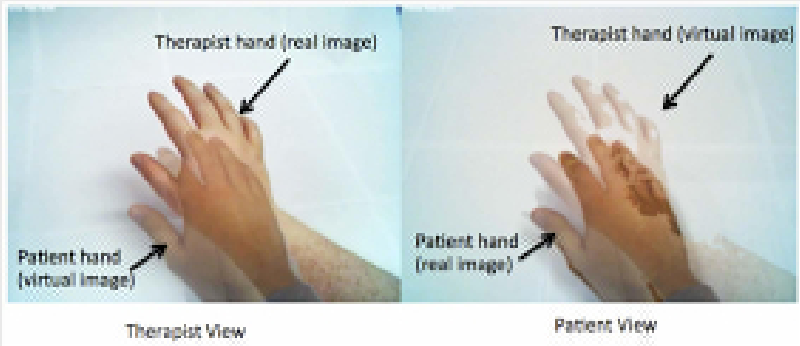
C. Poster

Ghost - Remote Collaboration solution for a Physiotherapist

Jonathan O'Duffy
HITLab NZ University of Canterbury
jonathan.oduffy@pg.canterbury.ac.nz

User Testing

Be involved and help design a new medical tool.



Concept

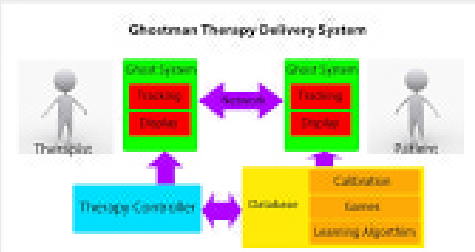
Imagine if you could see what your patient was doing hundreds of miles away.

That you could 'virtually' inhabit their body and guide and instruct them on rehabilitation exercises.

From the patients view, you are a ghost coming out of their body to guide them.

New Medical Tool

What is the best tracking and display solution?



Motivation

New Zealand currently spends $5.5 billion on musculoskeletal diseases.

Just an increase in 30% funding while a 200% increase in demand by 2026.

Serious Games

Use of games for motivation and doing home exercises.

Games are currently being tested in a 3 month home trial for parkinson disease in Australia.

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HITLabNZ
www.hitlabnz.org

D. Additional Background Information

Telerehabilitation
The author has spent some time working as a Telehealth officer within Australia. During this time the author reviewed technical documents on standards of telehealth placed by the government and interacted with healthcare and technical providers. These are some of the key points found:

1. **Government standards -** Place standards seem to contradict themselves. They will say, for example, Skype as a telecommunication tool is not suitable but then allow it to be used by clinicians. The reason for the creation of their standards in the first place is due to the sensitive nature around health data.

   Note: Skype was deemed unsuitable since the Government had selected an encryption protocol to be used. Since Skype has its own proprietary protocol (which it will not reveal), the Government has labeled it unsuitable.

2. **Equipment used -** The majority of solutions on offer or being used are off the shelf technology, such as Skype. From experience, there are some facilities who used a technical provider who just setup Skype on a laptop and in the end had a lot of technical problems which lead the healthcare facility to never use it again.

3. **Malpractice -** Healthcare providers are worried about being sued for malpractice from patients. This seems to be a confidence issue with technology and the unknown. The author's solution or suggestion was that the healthcare provider can always request the patient to travel if they are unsure. After the healthcare providers become more accustomed to technology, the amount of request for patient travel should decline.

4. **Doctors Learning -** Healthcare providers can view the technology as a learning curve and slowing them down. Why should the use or learn a new system when they have enough work as it currently standards. Introducing telerehabilitation at the student level seems a better approach than training healthcare providers practicing for a number of years.

5. **Funding -** There was an incentive done in Australia for the uptake of telerehabilitation. Unfortunately this was not implemented correctly and abused by healthcare and technical providers for making a quick profit: not all but some. This has lead to a change in approach based on patient distance to hospital and other factors.

One review of telerehabilitation [99] provides and in depth discussion on telerehabilitation and includes what are seen as advantages and disadvantages. The main concern from a policy-maker's point of view, is the cost associated with allowing such a system. While the initial purpose is to save cost and provide a higher quality of care to patients, the term Pandora's box has been used with regard to reimbursement of such a technology. They are worried that by making such a service available, there will be a sharp uptake from the public which will lead to a high level of reimbursement taking place.

Also worthy of note is the researchers breakdown of different forms of telerehabilitation.

1. **Home telerhab -** This involves a patient in a home environment communicating with a remote professional.
2. **Home rehab teleguided -** This involves a remote expert giving guidance to nurse or local assistance with a patient in a home environment.
3. **Community telerehabilitation -** This involves a patient in a healthcare facility communicating with a remote professional.
4. **Community rehabilitation teleguided -** This involves a remote expert giving guidance to nurse or local assistance with a patient in a healthcare facility.
5. **Community practitioner teleconsultation -** This involves multiple experts collaborating with a patient: this can be on x-rays the patient might have had. So the patients and patient doctor might communicate with an expert who will explain the x-ray.

Stroke

Based on this the researcher recommends a collaborative effort from a team of clinicians, engineers and neuroscientists to achieve maximum success. This collaboration is no small undertaking and comes with its share of known and unknown problems. The researcher also highlights that no occurrence of cybersickness was found among the patient population reported in studies reviewed.

E. Design Methodology Results

E.1. Lessons Learnt

This section provides a summary of the results gained from the design process outlined in Chapter 3.

Research Papers
Research papers were sought to address what is the nature of a stroke including cause and effects and response to traditional and new treatments. It was found that stroke can occur in one of two ways: a rupture or blockage of a blood vessel in the brain. The impact of the stroke on the individual depends on the severity of the stroke which is linked to the extent of damage caused to the brain. This in turn affects the level and types of treatments used on the individual. The most common methods of treatment fall into two categories:

- **Traditional -** focus on helping patients regain what they have lost.
- **Functional -** focus on helping patients adapt their lifestyles to their current condition.

New methods of treatment fall into the following categories:

- **Drugs -** focusing on helping a user with pain and relaxation of the muscles.
- **Robotic -** focuing on using machines to move the patient affected limbs in specific patterns to rebuild neural pathways.
- **Virtual Reality -** focusing on bringing the user into a 3D environment where additional information can be overlayed to help in the rehabilitation process.
- **Serious Games -** focusing on keeping the user engaged and motivated by con- verting repetitive exercises into a game so the patients experience is more enjoyable.

E.1.1. Observational Study

Due to the privacy issues around patient treatment, personal data, and medical history, direct observation was not possible. As an alternative, the author was able to observe home rehabilitation sessions via video recordings of an elderly stroke survivor to gain insight into the patient's world. The videos, which are available on YouTube, provided valuable insight into the challenges faced by post stroke patients in a home environment. There were four main points taken from these video observations:

- The users healthy side always assisted his stroke damaged side in any tasks undertaken.
- There are no time restrictions on tasks when you have a stroke.
- The damaged side is always used when possible such as helping to put on a shirt or getting out of a chair.
- Everyday tasks can help recovery and become a rehabilitation exercise: e.g turning pages in a newspaper.

E.1.2. Expert Interviews

Interview 1
Interviews where held with different groups to help guide the direction the development of the prototypes should take. The first interview conducted was with a senior engineer from Callaghan Innovations. Callaghan provide a wide range of physical devices and computer applications (serious games) to help stroke patients in their rehabilitation. At the start of the interview, the expert was presented with an information sheet and a list of questions. The information sheet provided background information about the Ghost project and the research current plan of development. There were a lot of questions asked as part of the structured interview (see appendix on structured interview questions). The following are the categories that the questions were grouped into on the questions sheet:

1. **Gamification -** questions about how to create a serious game for clinical use.
2. **Users Mood/Emotions -** questions about depression among stroke survivors and their motivation.

3. **Type of Data recorded -** questions about the types of data that should be collected and shown to patients and therapists.
4. **Diagnostic Tool -** to help detect neglect in stroke patients and how to implement such a tool.
5. **Evaluation Tool -** monitoring the patients condition.
6. **Built in Clinical Tests -** test therapist use in the real world implemented in the virtual world or through technology.
7. **Auto Calibration -** due to different patient conditions how to have the patient and technology work together.
8. **Stroke patients vs Other types of Patients -** is there anything different done between types of conditions i.e Stroke vs Parkinson disease.
9. **Rehabilitation and VR systems -** questions about how current systems fit into a patients life and how/where are they used.
10. **Assumptions and Personas -** What is process and what should be known when making health applications or serious games.

Out of this interview the following information was gained:

- Stroke work being done on animals.
- Variance of a severity of a stroke.
- Functional tasks an individual can perform.
- Where a patient starts and how they progress through different types of controllers.

Interview 2
A physiotherapist who deals with stroke patients was also interviewed at Callaghan Innovation. The same information sheet and questions from **Interview 1** were used. Information was gained about the process a person goes through after they wake up from their stroke. A simple task such as sitting up in bed can determine how a user's balance is affected: the patients can fall to one side and out of bed in severe cases. The first and most important phase in rehabilitation is to get the patient walking again. If they can walk, they can then go home and begin the rest of their rehabilitation from there. This therapist also answered questions around personas.

Interview 3
A psychologist at Burwood Hospital was interviewed. Valuable insight into the neurological effects faced by stroke patients as well as how this impacts their view and understanding of the world around them was gained. The altered view of the patient is called Visual Neglect and is explained below by the psychologist:

The patient sensory end organs are functional but the brain does not process information received. For example, a patient who previously suffered from arachnophobia and had a stroke. The patient outlined her fear of spiders and how she cannot be in the same room as them all the while a spider was climbing on the wall beside her which she failed to notice.

The psychologist also explained how association with objects can be lost. This can even extend to people saying their hands are not their own as they cannot connect the hands they see to themselves mentally. In such cases, they claim the hands to belong to other people and in one example, a woman claimed it was her husband, who had been dead for a number of years, in front of a therapist during a rehabilitation exercise.

Interview 4
Another interview was held with two people around knee rehabilitation. They talked about the tedious process involved in knee rehabilitation and the repetitive tasks/exercises associated with it. They went on to explain and show the software solution they created with their physiotherapist for future patients. The following is a screenshot of there software guiding someone through an exercise.

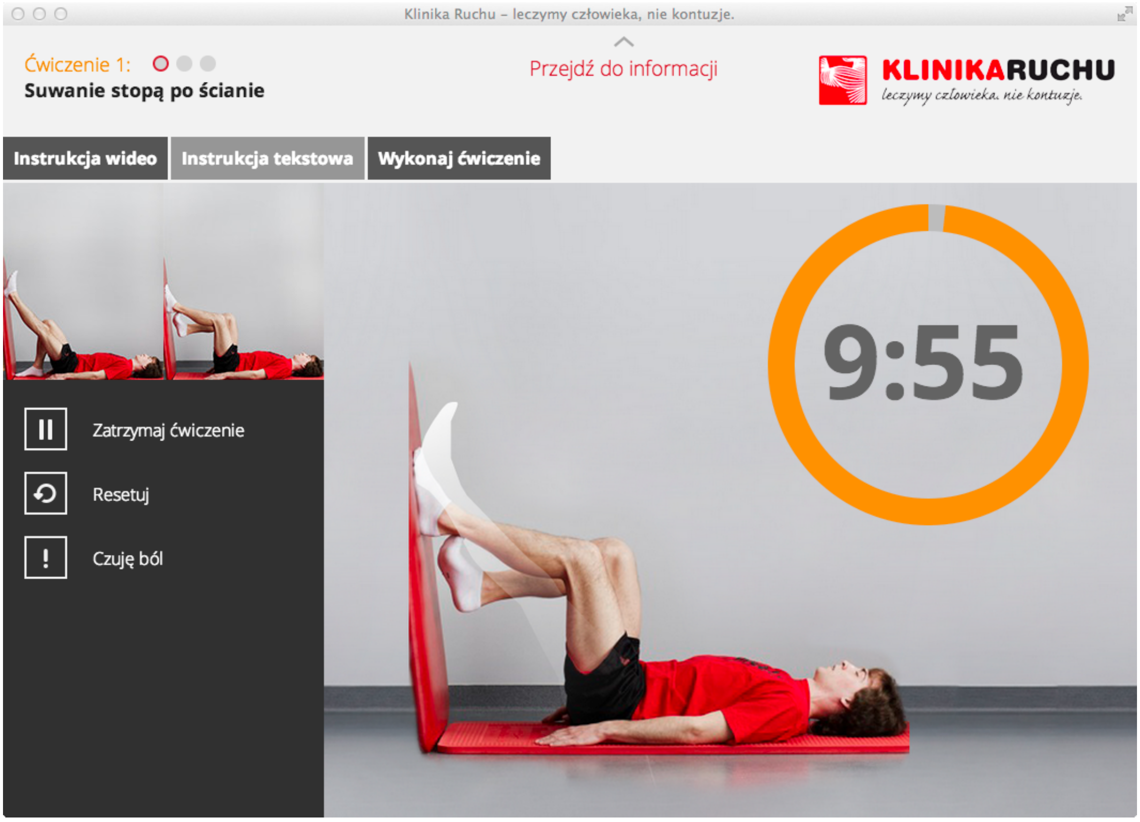

Figure E.1: Knee Exercise

The software solution had the following key points:

- **Video explanation -** This is used to explain to the patient their condition. It can also be used to give family and friends more information.
- **Program -** This provides a structured approach for the patients rehabilitation.
- **Exercises -** Each exercise has a video, animation, diagram flowchart and written explanation.
- **Timer -** There is a timer function incorporated into each exercise which acts as metronome for the patient to keep a rhythm during the exercise: 1 repetition at every 1, 2, 3. . . . or 10th second etc. It also tells the patient the amount of time to spend on each exercise.
- **Rest -** There is a rest period between each exercise.
- **Pain -** The patient can signal pain during an exercise that will result in an immediate rest period. If pain is signalled a second time, the patient is given

a longer rest period. A third signal of pain results in the patient being locked out of the system and they need to go see their physiotherapist, who will assess their condition and unlock the system for them.

- **Overtraining -** The system restricts the amount of daily exercises the user can do in a given day to prevent overtraining and injury.

Interview 5
A phone interview was held with the head psychologist from the Burwood Hospital. One topic was discussed, which was on the concept of creating a stroke jacket simulator for healthy people to role play as stroke patients during experiments. This discussion continued into how knights and kings wore lead sown into their clothes so that the weight of armour didn't hinder them in battle. It was recommended to be careful if a stroke jacket was used so that no participants were injured during the experiments: "you don't want to turn healthy people into patients". Details on collaborating with clinicians and Burwood Hospital were also discussed and how it could be achieved.

Active Arms
During the course of the Ghost research project, the author worked on a parallel research project on serious games for Parkinson's disease rehabilitation. Meetings were held fortnightly with clinicians who provided information about what was needed in a serious game as well as feedback on prototypes developed. Lessons learnt from the Parkinson research project were used in the creation of a similar serious game for stroke survivors.

E.1.3. Presentations

Presentations where given to several different groups regarding the purpose and nature of the Ghost research project. These presentations created a forum for providing feedback, gaining support and making people aware of the research project being undertaken.

Neuro Group
A presentation was done to a Neurological group at Hillmorton Hospital. The group consisted of different experts from different fields within the brain medical field: psychiatric doctors and psychologists. The presentation included the author's research proposal, early prototypes, and physical devices brought for the experts to provide feedback on. Feedback from the group, focused on the ability for the therapist and patient to be able to communicate verbally with one another while remotely collaborating. Concerns were raised about the potential cost of the

Ghost system, but the experts remained enthusiastic and impressed throughout the research presented.

Psychologists
A presentation was done to a group of psychologists at Burwood Hospital. The presentation was based on the previous presentation done to the Neuro group but included the author's plan for a stroke game and no devices were brought for experts to see. The group gave feedback on the topic of Māori stroke rehabilitation and concerns were raised around the cost in building the Ghost system. Support and encouragement was given with the author encouraged to seek patient trials for the research project.

Physiotherapists
The final version of the stroke game was presented to a physiotherapist group at Burwood Hospital. The therapists feedback was to see functional tasks on top of the gamification of rehabilitation exercises. An example was given of how stroke patients pick up a cup to drink from. If a cup was placed on a table in front of you, you would reach straight forward and pick the cup up. A stroke patient would hold their arm at odd angles while attempting to pick up the cup. This is due to the compensation that happens from having a stroke, so the patient must focus on performing the movement correctly. This lead onto the therapists emphasizing the need for patients to be monitored during an exercise to ensure they perform the exercise correctly.

Another example was given around Wii-fit games. At the start, patients would play Wii tennis with the correct movements but then realized they didn't need to perform the correct movements in order to win at the game. This resulted in patients moving closer to the TV and frantically waving the controller around without any focus on proper movements. This results in the patient tricking the system into giving positive feedback on performance. Therapists also raised concern, like the other groups, around the cost of the Ghost system. They also had limited time in being involved in user testing and expressed their enthusiasm to be involved in some form of online user testing to provide feedback.

Funding Group
The author attended a meeting/presentation for a medical group seeking advice on creating VR treatment for people who have become paraplegics. The process involves the patient becoming accustomed to using a wheelchair and the change in their lifestyle. The group has a three-stage process they would like to implement:

1. **VR Simulator -** To teach patients how to achieve daily tasks in a virtual world while still in the care of the hospital environment.
2. **Hospital Apartments -** The patients move to a nearby facility to monitor

and provide assistance while they adjust to the real world.

3. **Home -** Patients can go home and continue on with their lives.

The author presented Ghost and the research being undertaken to the group. The group were interested and discussed Ghost. The group then discussed a broad range of topics which the author provided background material on and answered further questions the groups had in VR treatments.

F. Website Screenshots

Account Creation

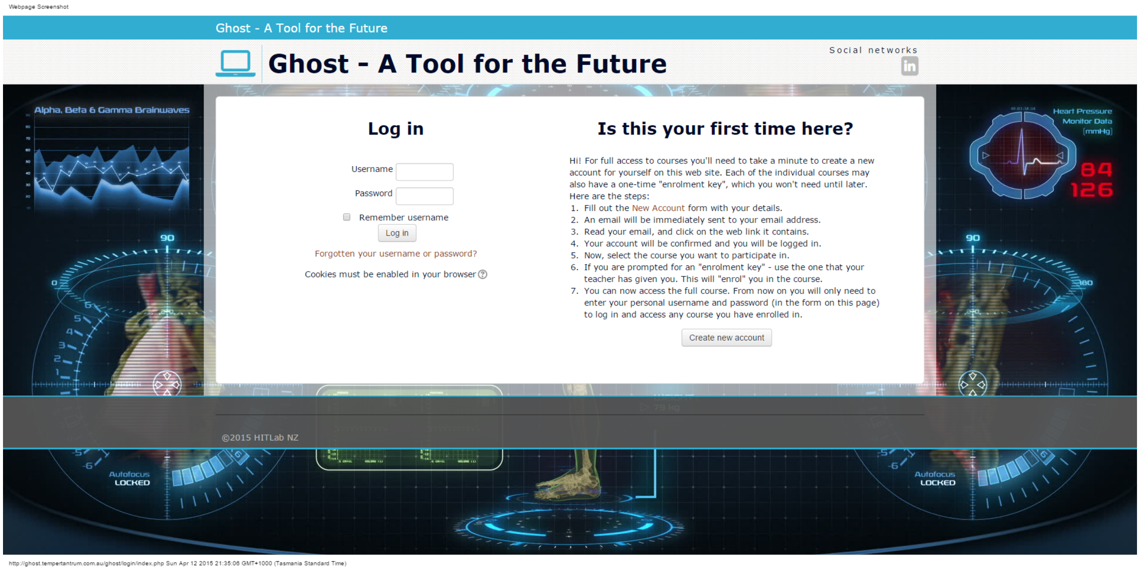

Figure F.1: Login and Account Creation

Figure F.2: Online and Local User Testing Sections

Demographics, and Unlocking Hidden Sections

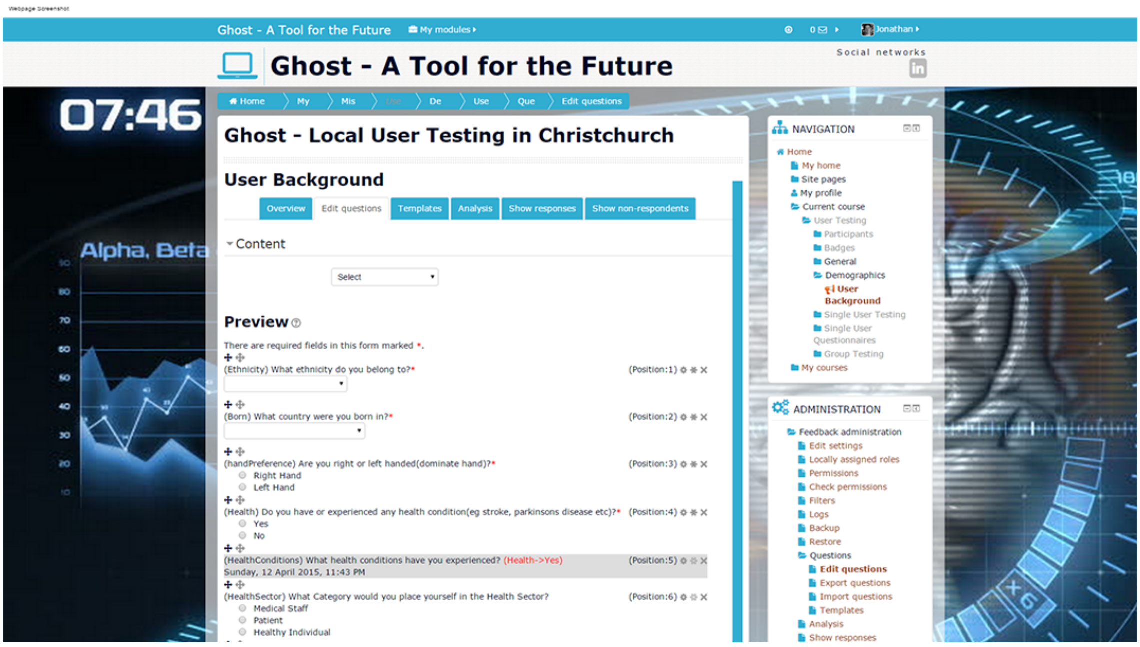

Figure F.3: Background Questionnaire

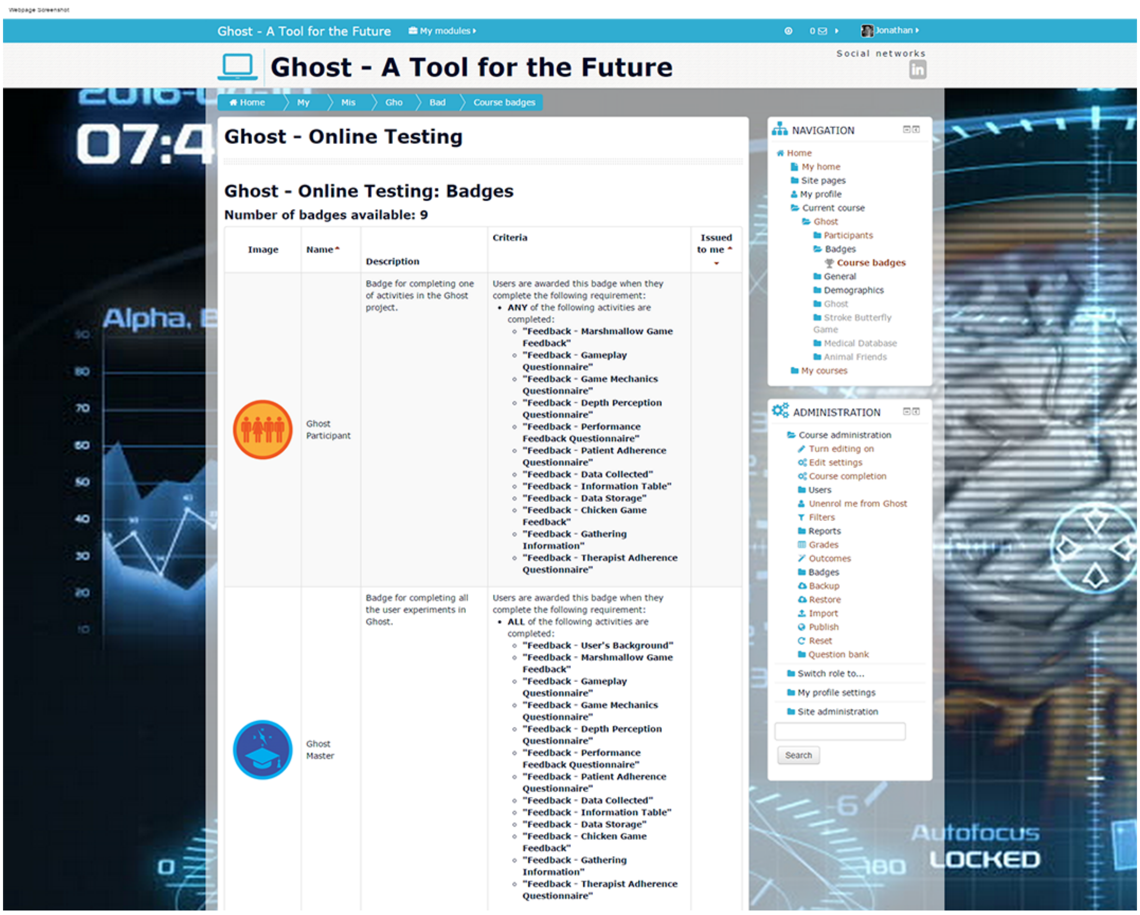

Figure F.4: Badges available as rewards

G. Ethics

Information Sheet

Department: HITLab NZ
Telephone: +64 3 364 2349
Email: jonathan.oduffy@pg.canterbury.ac.nz

November 2014

Ghost - Remote Collaboration solution for a Physiotherapist
Information Sheet for Ghost Participants

Overview

My name is Jonathan O'Duffy. I am a Master Student at HITLab NZ located within UC. My Masters Topic is "Ghost - a Remote Collaboration solution for Physiotherapists". The purpose of the research is to create a tool to assist Physiotherapist with the increasing demand placed upon the health sector from a growing an ageing population.

Participant Involvement

Your involvement in this project will be to test the various tracking and display solutions. This will be done by playing a mini game created by TemperTantrum called Butterfly. For a healthy individual, the average time to accomplish the game is around ~60second or less. The game will provide all the necessary instructions and I will be their to guide you through the experiment should any issues arise. But to summarise you will be required to collect 10 butterflies. You will play this game several times with each of the different tracking and display components. At the end of each game session you will be asked to fill out a form on your experience using the system.

After Experiment

As a follow-up to this investigation, you will be asked to to fill out a form on your overall experience of using the different tracking solutions and select which combination of tracking and display you feel is most appropriate for stroke survivors to use during rehabilitation. After you have completed the form, a short interview will be held to gain any other feedback you might have on your experience and what direction the research should take.

Risks

In the performance of the tasks and application of the procedures there are risks of Mental and physical fatigue. You may experience some mental fatigue from answering the questions and using the various components. There might be some physical fatigue experienced when using the various tracking solutions.

There wont be any physical danger involved at any time during this experiment.

Results

You may receive a copy of the project results by contacting the researcher at the conclusion of the project. Participation is voluntary and you have the right to withdraw at any stage without penalty. If you withdraw, I Jonathan O'Duffy will remove any information connected to you.

Some of the information might not be possible to remove due to the nature of storage. We create 3 forms of data from the experiment.

Log files - record of your performance. This can be manually deleted.

Database - this records your overall performance. This can be manually deleted.

Game Analytics - this is sending information to a web service were all collected information in anonymous. But unfortunately is not able to be removed once uploaded due to the nature of the service. In no way can this data be linked to you. It is simply recording some game elements that happen through your interaction with the mini game Butterfly.

Publication

The results of the project may be published, but you may be assured of the complete confidentiality of data gathered in this investigation: your identity will not be made public without your prior consent. To ensure anonymity and confidentiality,

Data being Stored

All data will stored on a secure server that is password protected and encrypted to ensure confidentiality. Each participant will receive an unique ID which their information will be stored under. This will be used to separate each participant data into its own collection so results can be compared in a simulated clinical manner. The simulation is trying to recreate a therapist monitoring their patients progress and is not intended to identify or single out any individual participant.

People with access to the data are the following : Jonathan O'Duffy and supervisors, medical staff assisting with the creation of Ghost.

The data will be held on to further the development of Ghost in future research projects.

A thesis is a public document and will be available through the UC Library.

Masters Degree

The project is being carried out as part of the HITLab NZ Master program and is required for Jonathan O'Duffy to be able to graduate and receive his Masters Degree. The project will be under the supervision of Mark Billinghurst, who can be contacted at mark.billinghurst@canterbury.ac.nz . He will be pleased to discuss any concerns you may have about participation in the project.

This project has been reviewed and approved by the University of Canterbury Human Ethics Committee, and participants should address any complaints to The Chair, Human Ethics Committee, University of Canterbury, Private Bag 4800, Christchurch (human-ethics@canterbury.ac.nz).

If you agree to participate in the study, you are asked to complete the consent form and return the consent form to the person conducting the experiment with you today.

Consent Form

Department: HITLab NZ
Telephone: +64 3 364 2349
Email: jonathan.oduffy@pg.canterbury.ac.nz

November 2014

Ghost - Remote Collaboration solution for a Physiotherapist
Consent Form for participant

Include a statement regarding each of the following:

I have been given a full explanation of this project and have had the opportunity to ask questions.

I understand what is required of me if I agree to take part in the research.

I understand that participation is voluntary and I may withdraw at any time without penalty. Withdrawal of participation will also include the withdrawal of any information I have provided should this remain practically achievable.

I understand that any information or opinions I provide will be kept confidential to the researcher supervisors, and medical staff and that any published or reported results will not identify the participants or their work environment. I understand that a thesis is a public document and will be available through the UC Library.

I understand that all data collected for the study will be kept in locked and secure facilities and in password protected electronic form. The information collected will be used as a reference for future work as Ghost is being developed.

I understand the risks associated with taking part and how they will be managed.

I understand that I am able to receive a report on the findings of the study by contacting the researcher at the conclusion of the project.

I understand that I can contact the researcher Jonathan O'Duffy (jonathan.oduffy@pg.canterbury.ac.nz) or supervisor Mark Billinghurst (mark.billinghurst@canterbury.ac.nz) for further information. If I have any complaints, I can contact the Chair of the University of Canterbury Human Ethics Committee, Private Bag 4800, Christchurch (human- ethics@canterbury.ac.nz)

By signing below, I agree to participate in this research project.

Participants Name:______________________________

Participants Signature:__________________________

Date (DD/MM/yyyy): ________/_______/__________

Please hand your form when completed to the researcher conducting the experiment

HUMAN ETHICS COMMITTEE

Secretary, Lynda Griffioen
Email: human-ethics@canterbury.ac.nz

Ref: HEC 2015/01/LR

7 January 2015

Jonathan O'Duffy
HITLab NZ
UNIVERSITY OF CANTERBURY

Dear Jonathan

Thank you for forwarding your Human Ethics Committee Low Risk application for your research proposal “Ghost”.

I am pleased to advise that this application has been reviewed and I confirm support of the Department’s approval for this project.

With best wishes for your project.

Yours sincerely

Lindsey MacDonald
Chair, Human Ethics Committee